Final report

OWMC
Ontario
Waste Management
Corporation

A provincial crown corporation.

ENVIRON
Counsel in Health and Environmental Science

SITE SELECTION PROCESS. PHASE 4A:

SELECTION OF A PREFERRED SITE(S)

Generic Risk Assessment

Volume I

Prepared for

Ontario Waste Management Corporation

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December 6, 1985

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Generic Risk Assessment
Volume 1 Report

Dear Sirs:

We are pleased to submit our Volume 1 Report on the Generic Risk Assessment. Appendices of supporting technical information will follow shortly.

Very truly yours,

M.P. Scott

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enclosure

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EXECUTIVE SUMMARY

PURPOSE OF THE REPORT

The Ontario Waste Management Corporation (OWMC) is engaged in a Facilities Development Process to establish a hazardous waste management facility for the Province of Ontario. OWMC's most highly ranked goal in the siting of the facility is the minimizing of risk to human health. A generic risk assessment was undertaken, therefore, as part of the OWMC siting process, in order to provide OWMC with a better understanding of the relative importance of siting factors related to human health risk. The generic risk assessment was designed to provide quantitative estimates of public health risks associated with emissions of toxic pollutants from the proposed hazardous waste treatment and disposal facility . The term "generic" indicates that at this stage the risk assessment has used a single set of generalized site parameters applicable to all sites rather than characteristics specific to each candidate site.

Volume 2 of this report includes appendices of supporting technical information.

SCOPE AND METHOD

In performing the risk assessment, consideration was given to both long-term exposures associated with normal facility operations, as well as short-term exposures associated with facility upset conditions or accidents, and off-site transportation accidents. For the long-term exposures, consideration was given not only to direct inhalation of air pollutants, but also to exposure via drinking water from ponds and cisterns; consumption of crops; and consumption of beef and milk from local livestock. Only direct inhalation was considered for the short-term exposures.

For each of these risk pathways, human exposure was assessed in a four step process which can be summarized as: (1) identification of significant sources of environmental release; (2) characterization of the selected releases in terms of the nature of the chemicals, frequency and duration of release, and magnitude of release; (3) modeling of pollutant transport in the environment; and (4) estimation of human dose by inhalation or ingestion.

Health risk was characterized in terms of both acute and chronic effects with consideration of exposure to both carcinogenic and non-carcinogenic chemicals. In the case of carcinogens, cancer risk values were calculated and compared to a lifetime cancer risk of one additional cancer per million people exposed. This value was used as an acceptable level of risk. For non-carcinogens, the estimated human dose based on the predicted exposures was compared to a toxicologically safe

level. The ratio of the safe level to the predicted exposure level was termed the adjusted margin of safety or AMOS value.

PREMISES AND POSTULATES

The risk assessment was undertaken for a proposed facility capacity of 300 000 tonnes per annum of special wastes. The details of the proposed facility and characteristics of the wastes to be accepted at the facility were provided by OWMC. Risk estimates were based on the preliminary design of the facility and did not include any provision for mitigation of potentially adverse health effects.

Throughout the risk assessment a series of conservative assumptions was made in defining the scenarios for the characterization of facility releases, environmental transport modeling and estimation of human dose. These assumptions were considered conservative in that they resulted in the selection of facility operating parameters and environmental conditions that would tend to overestimate the magnitude of human exposures experienced. As a result of these conservative assumptions, the predicted human health risks are likely overstated.

STATUS OF DATA

Data used in the risk assessment were provided from two principal sources: published literature on the toxicological behavior of chemicals in the environment -- their transport, fate and effect; and other consultant studies undertaken for OWMC. Two key data elements can be identified in

the risk assessment process: the types and quantities of chemicals emitted; and the effects of these chemicals on human health.

For characterizing emissions of potentially toxic pollutants, the risk assessment was based on the preliminary design of the facility and on available data on waste characteristics. While the design of the facility will be refined in subsequent stages of OWMC's Facilities Development Process, the existing design information was considered sufficiently detailed to quantify the magnitude and duration of emissions. Information on the frequency of facility upset conditions and accidents, however, was limited to qualitative estimates only.

Data on waste types to be managed by the proposed facility were based on a survey of 1000 industries in Ontario. A limited amount of quantitative data on waste constituents was available from this source. To account for lack of full information, chemical constituents of concern in individual waste streams were identified, and the most hazardous chemicals used to represent particular waste categories in a way which would tend to overestimate risk. It was not yet possible, however, to provide data on landfill leachate characteristics in a form which could be employed in a quantitative risk assessment.

In the case of the toxicological effects of the chemicals on human health, the risk assessment relied on a mixture of human experience and animal experiments. While there are limitations and uncertainties in extrapolating from such data, the use of appropriate safety factors and

mathematical models is an accepted approach that provides a systematic approach to evaluating scientifically the available data.

Overall, it was considered that the use of conservative assumptions and safety factors enabled meaningful and useful estimates of risk to be derived for the risk pathways addressed.

MAIN FINDINGS

In the case of short term exposures occurring as a result of episodic release events, the risk assessment was based on the potential for acute effects. Acute effects were considered to include very mild effects such as odor or minor irritation, although these should not necessarily be considered adverse to health. The potential for acute effects was considered significant when the AMOS value (defined as the ratio of a toxicologically safe level to the predicted exposure level) was less than one. The AMOS value was less than one in three cases: the incinerator stack scrubber failure, transportation spill and tank farm fire. In the case of the incinerator stack scrubber failure, further evaluation of the toxicological literature indicated that no adverse health effects would be expected, although slight odor or minor, reversible irritation effects might be experienced. For the transportation spill and tank farm fire, further evaluation indicated that potentially severe health effects could be experienced. Both events, however, are believed to have low probabilities of occurrence, and it should be emphasized that the severity

of the actual adverse health effect would be strongly influenced by such factors as distance of the human receptor from the spill or fire, the duration of exposure and the amount of toxic pollutant released. Also, it should be noted for the transportation spill that only 9% of the special wastes transported to the facility have the potential to cause effects under the spill conditions considered here.

In the case of chronic exposures, health risk was evaluated based on the magnitude of potential cancer risk associated with each exposure pathway. In all cases, the predicted cancer risks were equal to or less than one in a million (1×10^{-6}).

CONCLUSIONS

The risk estimates developed in the generic risk assessment are considered to overstate the incremental risk associated with OWMC's hazardous waste management facility. Although these risk estimates are appropriate for site selection purposes, they should not be considered as measures of absolute risk.

For short term events, the potential for adverse health effects was predicted only for the transportation spill and tank farm fire. The risks associated with these events were considered to be comparable and more significant than those for the incinerator scrubber failure.

For chronic emissions, the long term health risks, both individually and in combination, were all judged acceptable relative to the one in a

million cancer risk criterion established for this study. The risks from direct inhalation of both fugitive and stack emissions, however, were more significant than those from the indirect pathways of drinking of water from ponds and cisterns, consumption of contaminated crops, or consumption of contaminated meat and milk.

RECOMMENDATIONS

The health risk assessment provides quantitative data upon which comparisons of risk pathways can be made. It is recommended that these comparisons of risk pathways be used by OWMC to assist in the ranking of risk factors as input to the selection of a preferred site(s) for the proposed facility.

Further, it is recommended that a more detailed, site-specific risk assessment be undertaken for the selected site. To facilitate this more detailed risk assessment, consideration should be given to improving the waste characteristics data base, both for the wastes to be received by the facility and for the leaching characteristics of the solidified wastes to be disposed of in the engineered landfill. Also, a hazard analysis of the facility should be undertaken to provide more detailed information on potential accidents and upset conditions, and, in particular, on their frequency of occurrence.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND AND PURPOSE

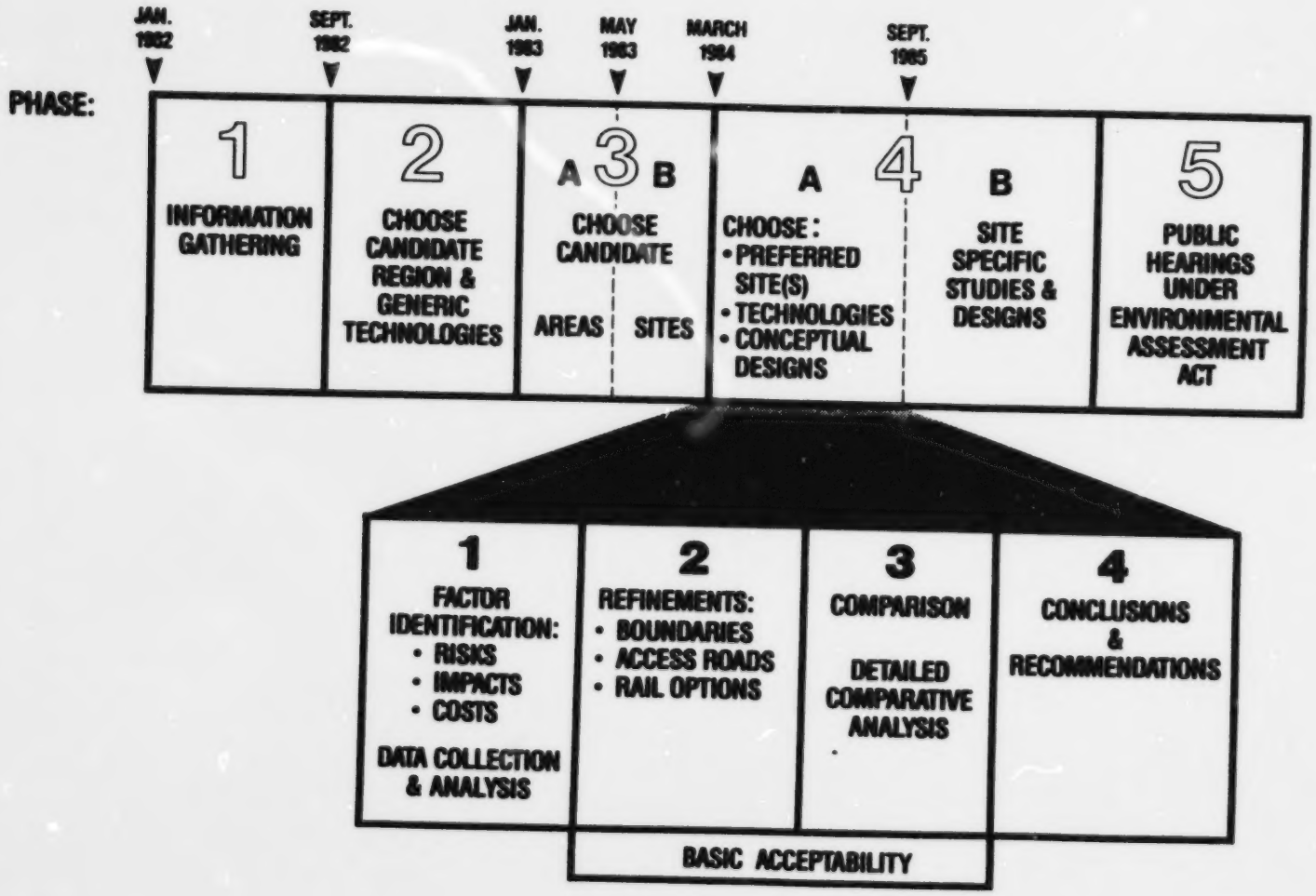
The Ontario Waste Management Corporation (OWMC) is engaged in a Facilities Development Process to establish a hazardous waste management facility for the Province of Ontario (OWMC, 1985). The Facilities Development Process consists of five phases designed to move OWMC through the process of selecting a site(s) and designing the facilities in preparation for the hearings and approval process required prior to construction (see Figure 1). Throughout this process the primary goal of OWMC has been and continues to be the minimizing of risk to public health.

A major part of the Facilities Development Process is the selection of a preferred site(s) for the proposed hazardous waste management facility. This site selection process has involved a series of successively more detailed steps to identify potentially suitable sites. At the end of Phase 3 of the Facilities Development Process, eight candidate sites were identified located in the Niagara Falls, West Lincoln, Mississauga and Milton areas.

To select a preferred site(s), Phase 4A of the Facilities Development Process consists of a comparative evaluation of the eight candidate sites (M.M. Dillon, 1985a). Three major study components are addressed within

FIGURE 1

FACILITIES DEVELOPMENT PROCESS 4A



this comparative evaluation - Risks, Impacts and Costs. This summary report is concerned with those issues related to human health risk associated with exposure to toxic substances.[1] Within this category, the site selection process identifies the following risk factor groupings with regard to the potential effects of a waste management facility (M.M. Dillon, 1985a):

- Transportation Risks
- Air Dispersion/Air Quality Risks
- Risks Related to Hydrogeologic Suitability
- Risks Related to Surface Water Suitability

Risks in these factor groupings are associated with potential releases of chemicals during the normal operation of the facility, such as fugitive and stack emissions; with releases that might occur during facility upsets or accidents; and with releases caused by transportation spills. These releases can result in contamination of air, surface water, groundwater and soil. Human exposure to the released contaminants can occur through inhalation, ingestion, or by skin absorption. A number of specific risk pathways (e.g., direct inhalation of contaminated air or ingestion of contaminated crops) have been selected for analysis. Once the risk associated with each pathway is understood, a comparison can be made to assist in the weighting of siting factors related to human

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[1] Appendices of supporting technical information are presented in Volume 2 of this report.

health. The purpose of the generic risk assessment is to provide the data on which such comparisons can be made. The term "generic" indicates that at this stage the risk assessment has used a single set of generalized parameters applicable to all sites rather than characteristics specific to each candidate site. A site-specific risk assessment should be undertaken as part of the environmental impact assessment of the preferred site.

1.2 SCOPE OF RISK ASSESSMENT

The risk assessment process was designed to provide estimates of human health risk associated with exposure to toxic pollutants via selected risk pathways. The pathways selected for quantitative analysis were chosen from the risk factors identified by OWMC for comparison of siting options. These risk factors are summarized in Table 1, and discussed further in other Phase 4A reports (M.M. Dillon, 1985a; OWMC, 1985). The selected pathways were: (1) those which were believed to have the potential to contribute most significantly to public health risk; (2) those which would address specific expressed public concerns; and (3) those for which data were in a form suitable for quantitative risk assessment. The pathways selected consisted of the following:

1. Exposure resulting from normal facility operations:
    a. Direct inhalation of air pollutants,
    b. Ingestion of contaminated drinking water from ponds and cisterns,
    c. Consumption of contaminated crops,
    d. Consumption of contaminated meat from livestock which ingested chemical contaminants in their food and water,

TABLE 1

RISK FACTORS FOR COMPARISON OF SITING OPTIONS

TRANSPORTATION
• Annual province-wide hazard-based spill index of OWMC generated transport
• Annual province-wide accident involvement of OWMC generated transport
• Transportation risks on local and regional access roads due to accident involvements of OWMC generated transport
• Transportation risks on local and regional access roads due to hazard-based spills of OWMC generated transport
AIR DISPERSION/AIR QUALITY
• Risks from direct inhalation of emissions - chronic
• Risks from direct inhalation of emissions - acute
• Risks from consumption of cistern and pond water
• Risks from consumption of crops and livestock
HYDROGEOLOGIC SUITABILITY
• Capability of providing natural containment
• Ground water use
SURFACE WATER SUITABILITY
• Susceptiblity of site to flooding
• Potential for water use interference

Source: M.M. Dillon, 1985a.

e. Consumption of contaminated milk from livestock which ingested chemical contaminants in their food and water.

2. Exposures resulting from facility upset conditions.

3. Exposures resulting from facility accidents.

4. Exposures resulting from transportation accidents.

Each of the selected pathways noted above is associated with specific air emissions from the facility or from a transportation accident. Releases to groundwater and the potential for exposure initially were to be considered as well. However, the groundwater pathway was not considered because sufficiently detailed data on the potential leachate quality from the landfill and on site-specific hydrogeology were not available at this time. Information on the site-specific hydrogeology will be available at a later stage in OWMC's Facilities Development Process, when detailed testing of the preferred site(s) has been undertaken. In the case of the leachate quality, it is recommended that the leaching characteristics of the solidified wastes to be deposited in the landfill be investigated further. In the meantime, the focus of the groundwater pathway analysis has been on a qualitative comparison of siting options as described by Gartner Lee Associates (1985).

The exposures considered potentially significant as a result of normal facility operations were both fugitive emissions from the handling of materials at the facility and incinerator stack emissions from the combustion of waste material. Each of these can contribute to a direct impact on air quality and thus were considered significant in evaluating the potential for the direct inhalation of chemical contaminants. It

should be noted that the point of maximum impact created by fugitive and stack emissions occurs at different locations, and that the health risk assessment considered the highest potential for exposure in each case. This approach, the use of conservative assumptions, is consistent with the approach used throughout the risk assessment process.

In addition to creating direct impacts on air quality and thus potential human exposures, both fugitive and stack emissions can lead to indirect human exposures. As part of the risk assessment, the potential ingestion of contaminated drinking water from ponds and cisterns was considered. In a similar manner, the potential for ingestion of contaminated crops was considered, and the ingestion of contaminated meat and milk from livestock raised on contaminated crops was evaluated.

Consideration was given also to exposure resulting from facility upset conditions and accidents, and transportation accidents. Each of these events can result in emissions of volatile organic chemicals. Direct exposures only were considered for these emissions, and health risk was assessed at the point of maximum exposure in each case.

1.3 RELATIONSHIP TO OTHER SITE SELECTION ACTIVITIES

The generic risk assessment forms part of a series of studies undertaken by a team of consultants. The risk assessment is linked to these other site selection activities in that the bases for many of the inputs to the risk assessment were provided by other consultant studies. For example, the sources of potential releases were identified by review of the

proposed facility design (Monenco, 1985a) and surrogate chemicals for modeling these releases were selected by an analysis of a data base on waste types expected to be received at the facility. The development of the database is described in a report prepared for OWMC by Canviro Consultants, Ltd. (1985). Other inputs to the risk assessment were provided directly by other consultants, e.g. the air dispersion modeling of chemical releases and the estimation of the deposition rates for these chemicals were conducted by the Ontario Research Foundation. These inputs to the risk assessment process and how they were used are summarized in Table 2.

The overall purpose of the risk assessment was to assist in the weighting of siting factors related to human health. To accomplish this, it drew on data from studies by other consultants and in turn generated risk estimates for use by these other consultants. These risk estimates were used as part of the overall ranking of risk factors (M.M. Dillon, 1985a) and particularly in the consideration of atmospheric dispersion (ORF, 1985b).

1.4 ORGANIZATION OF REPORT

This report is organized into seven chapters.

- Chapter 1, Introduction (this chapter), provides an overall description of the risk assessment process and why it was undertaken.

TABLE 2

INPUTS TO RISK ASSESSMENT FROM OTHER CONSULTANT STUDIES

Input Data	Source	Analysis undertaken in Risk Assessment
Facility design	Monenco	Identification of potential release sources
Waste stream characteristics	Canviro	Selection of surrogate chemicals
On-site gas emissions and calculations	Monenco	Estimation of chemical-specific emissions
Empirical emissions data	ORF	Estimation of chemical-specific emissions
Definition of facility upset and accident conditions	M.M. Dillon Monenco	Estimation of chemical-specific emissions
Transportation spill frequency	M.M. Dillon	Estimation of exposure probability for spill events
Air dispersion modeling	ORF	Estimation of chemical concentrations at exposure points
Chemical deposition rates	ORF	Estimation of chemical concentrations in cisterns and ponds.
		Estimation of chemical concentrations in soil and vegetables.
Livestock and crop production data	Ecologistics	Estimation of chemical concentrations in vegetables, meat and milk

- Chapter 2, The Risk Assessment Process, provides a description of the principles of risk assessment and discusses the limitations inherent in any risk assessment. Also included is a discussion of the application of risk assessment to the OWMC facility siting process.

- Chapter 3, Characterization of Releases, contains a description of the characteristics of the facility and the major sources from which releases may occur. Each release subsequently is evaluated based on the use of surrogate chemicals.

- Chapter 4, Direct Exposures to Facility Emissions, presents the analyses of the risk pathways involving direct inhalation of fugitive and incinerator stack emissions as well as those resulting from the direct inhalation of air emissions from facility upsets and accidents. In each case the risk pathway is defined, an assessment of human exposure is provided, and human health risk is characterized.

- Chapter 5, Indirect Exposures to Facility Emissions, presents an analysis of health risk associated with the ingestion of contaminated water from cisterns and ponds, and the consumption of contaminated food from either crops, meat or milk. The pathways are defined, human exposure is evaluated, and health risk is characterized.

- Chapter 6, Exposure via Transportation Spills, presents an analysis of the health risk associated with the inhalation of volatile organic compounds released in transportation spills. The pathway is defined, an estimate of spill frequency is developed, human exposure is evaluated, and health risk is characterized.

- Chapter 7, Conclusions, presents a summary of the findings of the risk assessment, and an analysis of the relative importance of these risks to each other and other common risks.

The description of the risk assessment process requires the use of certain terminology and technical language. Clarification of this terminology and technical language is provided in the report where appropriate, and a glossary of all technical terms follows the Conclusions of the report.

CHAPTER 2

THE RISK ASSESSMENT PROCESS

2.1 PRINCIPLES OF RISK ASSESSMENT

For the purposes of this study, human health risk can be defined as the probability of injury, disease, or death as a result of exposure to toxic substances. It can be expressed in numerical terms, and takes values from zero (absolute certainty that harm will not occur) to one (absolute certainty that it will occur). For some types of chemical exposures, risks can be estimated from historical data on the relationship between an activity and the incidence of adverse outcomes. For example, extensive documentation may exist on deaths and other types of injuries resulting from accidental poisoning by household products, pesticides, and therapeutic agents. These types of chemical exposures of short duration are termed acute exposures, and generally are associated with immediately observable effects. These effects may cease when the exposure ceases, i.e., acute effects, or they may persist beyond the period of exposure in which case the effects would be termed chronic.

Other types of chemical exposures do not produce immediately observable effects and it is only over a relatively long period of exposure, i.e., a chronic exposure, that adverse health effects may result. These adverse health effects are typically chronic effects, and generally are evaluated from animal studies.

Exposures associated with an operating hazardous waste management facility may be both acute, e.g., accidental emissions of relatively short duration and chronic, e.g., continuous emissions from fugitive sources. It is the purpose of this chapter to describe the process used to evaluate human health risks from such exposures.

In general, the risk assessment process consists of the following components:

- exposure assessment
- hazard evaluation
- risk characterization.

EXPOSURE ASSESSMENT

Knowledge of the routes, magnitude and duration of exposure to environmental chemicals is the first component of risk assessment. Human exposure is assessed typically in terms of the dose of chemical taken into the body, commonly in units of milligrams per kilogram of body weight per day. For certain gaseous pollutants, particularly those which act as irritants, exposure may be assessed in terms of the concentration to which an individual is exposed, commonly in milligrams per cubic metre or parts per million, and the time of exposure.

In the context of hazardous waste facilities, the starting point for assessing exposure is identifying the significant environmental releases associated with the waste management practices employed. For example, incineration may be characterized by emissions of incompletely combusted

chemicals or hazardous combustion products, while physical/chemical treatment may be characterized by spills and fugitive emissions.

The next step is to identify possible routes of human exposure. Three routes -- inhalation, absorption and ingestion -- exist via which humans can become exposed to pollutants in their environment. These pollutants can be present in various environmental media such as air, surface water, groundwater, and soil. Through contact with these media, individuals can ingest, inhale or absorb pollutants and thus become exposed. If the concentrations of pollutants in each of these media are known or can be predicted and the extent and frequency of human contact with each is known, then human exposure to each pollutant can be estimated. To this end, environmental fate and transport models can be used to predict the concentrations of pollutants in the various environmental media likely to result from the operation of a hazardous waste management facility. To calculate the human dose that would result from contact with these pollutants, certain standard conventions are commonly applied. These conventions assume average values for the intake of food, water, etc., and also make assumptions regarding the absorption of pollutants within the human body. Estimates of human dose or pollutant concentration and exposure time calculated in this way can be applied to both short-term and long-term exposure assessments.

HAZARD EVALUATION

All chemical substances, whether natural or man-made, have the potential to cause some form of biological injury, disease or death under certain conditions of exposure. The term used to describe this inherent potential

is toxicity, and the purpose of the hazard evaluation phase of risk assessment is to collect and evaluate information on the inherent toxic properties of the chemicals of interest. This information may relate both to acute and chronic toxic effects. Such information can be collected from two principal sources: epidemiological or clinical investigations, and experimental studies involving laboratory animals or other biological systems.

In addition to identifying the types of toxicity associated with a substance, it is also necessary to identify dose-response relationships. The frequency with which toxic effects appear in an exposed population (i.e., the risk) increases with increasing exposure or dose. In many cases, the types of toxic effects change as exposure increases, becoming more severe with increasing exposure and conversely, less severe with decreasing exposure. Thus, it is important to understand how the nature and magnitude of risk relate to any given dose.

A major dose-response issue is that of thresholds. A threshold dose is that which must be exceeded before a toxic effect is observed. The appearance of most toxic effects requires that a threshold be exceeded, although for some -- notably carcinogenic effects -- there appears to be a basis for rejecting the threshold hypothesis. In fact, carcinogenic risk assessment, as currently practiced, generally assumes the absence of thresholds. It should be noted, however, that this premise may not hold for all carcinogens (NRC, 1980).

One of the critical uses to which dose-response data are put is the identification of the dose at which no adverse response is observed in a population exposed to a toxic substance. This dose (called the "no-observed adverse effect level," NOAEL) may approximate a threshold dose for the population under study, and is generally taken as the starting point for risk assessment for chemicals that are assumed to operate by a threshold mechanism (NRC, 1980; Food Safety Council, 1980). This general approach applies to both acute and chronic exposures, although the dose-response data may be determined from different types of studies. Data for chronic exposures are generally derived from animal studies, although in some cases, particularly for exposure by inhalation, human data may be available from occupational settings. For acute exposures, human data are usually more available from clinical tests or accidental exposures, supplemented as necessary by information from animal studies.

In reviewing the dose-response data, it should be realized that not all measurable effects caused by chemical exposures are adverse to health, although for chronic exposures the no-observed-adverse-effect-level (NOAEL) typically is considered equivalent to a no-observed-effect-level (NOEL). For acute exposures, however, individuals may detect odors or experience certain minor forms of irritation which are reversible and will cease after exposure. These effects usually occur at low exposure levels long before adverse health effects are experienced. Thus, in evaluating the hazards for acute toxicants, a distinction can be made between the threshold for the effects that can impact human health (indicated by the

NOAEL) and the threshold for those effects that are expected to occur without adverse health impacts (indicated by the NOEL).

For carcinogens, the dose-response data are usually treated differently. To predict low dose risk from high dose/high risk data, which is the usual situation, it is necessary to apply certain mathematical models to the dose-response data (Food Safety Council, 1980; Klaasen, D.J. and Doull, J., 1980; IRLG, 1979). These models allow prediction of low dose risks, and their application yields an estimate of cancer risk per unit of dose (e.g., incidence of cancer at a dose of 1 mg/kg body weight/day, for continuous lifetime exposure). The hazard evaluation phase of risk assessment thus results in a presentation of NOAELs and/or NOELs for non-carcinogens, and of estimates of risk per unit dose (unit risks) for carcinogens.

RISK CHARACTERIZATION

Having evaluated the inherent hazard posed by a chemical agent, and the routes, magnitude and duration of the exposure, a quantitative measure of risk may be developed. A distinction is generally made here between the way in which risk is characterized for (1) chronic exposure to carcinogens; (2) chronic exposure to non-carcinogens; and (3) acute exposures.

For chronic exposures to non-carcinogens, it has become the practice to divide the experimentally-determined NOAEL by a large "safety factor" to estimate acceptable human doses. The application of the safety factor is based on the notion that there is likely to be a much wider range of

susceptibilities in the human population than there is in the test animal group from which the NOAEL is obtained. The choice of safety factors depends on the nature and uncertainties of the toxicity test data. If the NOAEL was derived from a well-conducted animal chronic toxicity study, and has been carefully identified, the usual safety factor for estimating an "acceptable daily intake" (ADI) for humans is 100 (Food Safety Council, 1980; Federal Food, Drug and Cosmetic Act). Larger safety factors are commonly introduced when experimental data are lacking or limited, or when the effects of exposure are especially serious (Calabrese, 1983).

Risk characterization for non-carcinogens thus takes the form of determining the margin-of-safety (MOS) -- the numerical value derived when the experimental NOAEL is divided by the human dose. Under this system, the smaller the value of the MOS, the larger the risk. If there is virtually no MOS, it might be concluded that many members of the exposed population are at high risk of experiencing the form of toxicity experienced by the test animals at doses above the NOAEL. At a small fraction of the NOAEL, it is likely that the risk is very low and may be zero, although there is no practical way to determine whether this is actually the case.

For chronic exposures to carcinogens, the risk is characterized as the unit cancer risk. The risk per unit dose is multiplied by the actual daily lifetime dose experienced by people to derive an estimate of risk. In this case, an explicit risk is estimated, which takes values between zero and one. The definition of acceptable risk, e.g., 10^{-5}, 10^{-6}, etc., then becomes a matter of judgement or policy rather than a scientific

determination. The use of numerical estimates of risk derived in this manner as decision-making tools for separating significant risk from insignificant risk has become common practice (NRC, 1980a; Rodricks, 1984; Rodricks and Taylor, 1983).

For acute exposures, criteria for short-term exposure limits for air pollutants have been developed by the National Academy of Sciences (NAS) (1979). NAS defines short-term exposure as a single exposure, usually lasting 60 minutes or less, but never more than 24 hours. The approach used depends on a substance-by-substance evaluation of each chemical. For compounds for which reliable human and animal data predict little chance of irreversible effects from a single exposure, exposure limits can be established directly from the human data with no additional safety factor. If the human data are weak but the animal data strongly suggest irreversible effects are unlikely from a single exposure, then a safety factor can be applied depending on the quality of the data. When cancer or some other irreversible effects are expected, then several possible approaches can be used. These include:

- Establish an exposure limit for the general population based on an appropriate safety factor as would be done for noncarcinogens; or, depending on the nature of the chemical, include specific warnings to particular segments of the population that may be at additional risk, e.g., in the case of exposure of pregnant women to a possible teratogen; or

- For carcinogens, use quantitative risk assessment to recommend an exposure level that provides a defined level of risk (i.e., 10^{-5}, 10^{-6}, etc.).

The appropriate choice depends upon the observed toxicological behavior of the chemical under review.

2.2 LIMITATIONS AND UNCERTAINTIES OF THE RISK ASSESSMENT PROCESS

Associated with the risk assessment framework are a set of uncertainties which can be considered in two categories: (1) those that are an inherent part of the current state of knowledge and cannot be improved upon; and (2) those that result from data deficiencies and can be improved upon by increased levels of sophistication or data input. Uncertainties of the first type are principally associated with hazard evaluation and include:

- Extrapolation of toxicity data from animals to humans
- Extrapolation of high dose/high risk data to low dose cases
- Lack of data on biological interaction and enhancement of toxic effects from combined exposures associated with hazardous materials.

Uncertainties of the second type apply more to the exposure assessment than to hazard evaluation. They can be improved upon to some extent by increased data collection (e.g., the development of additional waste characteristics data, the use of measured rather than estimated values for emissions or environmental concentrations), by the use of more

sophisticated environmental fate and transport models, or by more detailed data on environmental conditions. Alternatively, where available data are limited, uncertainties can be handled, like the toxicological data limitations, by the use of safety factors or conservative assumptions.

While these limitations and uncertainties should be noted in the interpretation of the results of any risk assessment, the risk assessment methodology provides a systematic approach to evaluating scientifically the available data for assessing public health risk. With the use of appropriate assumptions and data inputs, risk assessment can provide a meaningful and useful measure of the potential for adverse health effects as a result of exposure to toxic substances.

2.3 APPLICATION OF THE RISK ASSESSMENT PROCESS TO THE OWMC FACILITY

The application of the risk assessment process to the OWMC facility is described in the following section in terms of the three components outlined previously: exposure assessment, hazard evaluation and risk characterization.

EXPOSURE ASSESSMENT

The exposure assessment consisted of the following four major steps:

(1) Identification of significant sources of environmental releases;

(2) Characterization of releases in terms of

- frequency and duration,
- chemicals to be modeled, and
- magnitude of release;

(3) Application of transport models to predict environmental concentrations;

(4) Estimation of human dose by inhalation or ingestion.

Throughout these steps in the exposure assessment, a series of conservative assumptions was made. These assumptions were considered conservative in that they resulted in the selection of facility operating parameters and environmental conditions that would tend to overestimate the magnitude of human exposures experienced. For example, data on waste stream characteristics were used to select the most hazardous waste stream within a class of wastes, and that class was modeled as if it were composed entirely of the most hazardous stream. Similarly, human exposure was estimated at the point of maximum exposure for all risk pathways considered. These and other conservative assumptions used in the exposure assessment are summarized in Table 3. Based on the use of such assumptions, the exposure estimate can be considered to overestimate actual exposure for an individual living or working in the vicinity of the facility.

The first step of the exposure assessment was to identify the significant sources of releases from the facility. The various operating units planned for the facility were reviewed by the engineering consultants (Monenco, 1985b), and a series of releases identified for further evaluation.

Second, the selected releases were characterized in terms of frequency and duration, the chemicals emitted and the magnitude of the

TABLE 3

ASSUMPTIONS USED IN EXPOSURE ASSESSMENT

CHARACTERIZATION OF RELEASES

- Waste classes represented by waste streams of highest hazard
- Waste streams represented by constituent of highest hazard
- Releases based on 300 000 t/a facility capacity
- Incinerator destruction and removal efficiency (DRE) of 99.99%
- Fugitive emissions based on all waste handled by each unit operation
- Transportation spills based on traffic accident involving loss of entire contents of truck
- Tank farm fire based on "boiling off" entire contents of tank
- No mitigation measures included beyond normal practice

POLLUTANT TRANSPORT MODELING

- Atmospheric conditions typical of Niagara region adopted for long term air dispersion modeling
- F stability conditions (worst-case) adopted for short term air dispersion modeling
- Scrubber failure emissions modeled as a truncated plume
- Plant uptake of all chemicals from soil based on highest partition coefficient recorded in literature surveyed

DOSE ESTIMATION

- All dose estimates based on exposure of off-site populations at point of maximum concentration
- Long term direct exposures based on continuous exposure over 30 year operating period
- Long term direct exposures to non-carcinogenic chemicals based on maximum two-week concentrations.
- Indirect exposures based on consumption of leafy vegetables, livestock products and water taken from point of maximum exposure
- Short term direct exposures from facility upset conditions and accidents based on exposure for duration of release
- Short term exposures from transportation spills based on exposure period of one hour

emission. The magnitude of the emissions was based conservatively on the maximum capacity of the facility, 300 000 t/a. Consideration was given to both long term releases under normal operating conditions as well as short term releases generated by upset conditions and accidents (both on-site and off-site).

Chemicals for each of these release types were chosen using a degree of hazard approach, whereby each category of waste was represented by the waste stream of highest hazard, and each waste stream represented by the chemical constituent of highest hazard. The approach accounts for the total quantity of wastes by assuming that the quantity of the highest hazard waste stream is equal to the quantity of the entire waste category. The degree of hazard approach was based on the toxicity, volatility and relative amount of each chemical expected at the facility, and was considered a conservative means to allow for some of the deficiencies in the data base for waste streams to be accepted by the facility. Emission rates for the selected chemicals were then estimated by a combination of empirical observations from comparable facilities (ORF, 1985a), and by engineering calculations (Monenco, 1985b).

The third step in the exposure assessment was the selection and application of appropriate models to predict multimedia environmental concentrations for the selected pathways, i.e., for direct exposures from inhalation and (for the long term releases) indirect exposures through consumption of local leafy vegetable crops, pond and cistern water, beef and milk.

In each case, conservative assumptions were used in the exposure assessment methodology: for long term releases, exposures were based on continuous exposure at the point of maximum concentration for a 30-year operating period of the facility, whereas a 20-year operating period is used in other Phase 4A site selection studies. In the case of short term releases, exposures were based on the most hazardous waste stream handled at the facility and an exposure period equal to the duration of the release.

The predicted chemical concentrations in air, cistern and pond water, beef, milk and leafy vegetables were then used as input to the final step of the exposure assessment: the calculation of the daily human dose obtained from various multimedia exposures. The dose calculations utilized standard dietary and metabolic assumptions for an average man doing light work as shown in Table 4. While more severe assumptions for the exposed populations could have been made, e.g., children, or adults engaged in heavy work, these were not adopted since they were considered less representative of the general population surrounding the candidate sites.

HAZARD EVALUATION

The hazard evaluation component of the OWMC risk assessment generated a series of toxicity profiles for the chemicals selected for modeling. These profiles are presented in Appendix A (see Volume 2 of this report). Each toxicity profile was prepared to reflect the type of exposure predicted for that chemical, i.e., chronic or acute (as described in Chapter 3). For chronic exposures to known carcinogens, the Unit Cancer

TABLE 4

STANDARD ASSUMPTIONS FOR HUMAN DOSE CALCULATIONS

Body weight, kg	70[a]
Breathing rate, m^3/h	1.7[b]
Water consumption, L/d	2.0[c]
Leafy vegetable consumption, kg/d	0.046[d]
Beef consumption, kg/d	0.139[e]
Milk consumption, kg/d	0.383[e]

Notes:

(a) National Institute for Occupational Safety and Health (NIOSH). 1980. Registry of Toxic Effects of Chemical Substances. 1979 Edition. Volume 1. DHHS (NIOSH) Publication No. 80-111.

(b) Altman, P.L., and Dittmer, D.S., eds. 1972. Biology Data Book, Second Edition. Federation of American Societies for Experimental Biology, Bethesda, MD. (Value used represents a man doing light work).

(c) United States Environmental Protection Agency (USEPA). 1980. Ambient Water Quality Criteria Documents. Office of Water Regulations and Standards, Criteria and Standards Division, Washington, D.C. (e.g., Ambient Water Quality Criteria for Phthalate Esters, EPA/440/5-80-067, PB81-117780).

(d) National Research Council of Canada (NRCC) 1979. Effects of Cadmium in the Canadian Environment. Publication No. NRCC 16743 Ottawa, Canada.

(e) United States Environmental Protection Agency (USEPA). 1978. Update of Food Factor Tables. Memo dated May 1, R.D. Schmitt, Toxicology Branch.

Risk (UCR) values used in the risk assessment were taken from the assessments prepared by the United States Environmental Protection Agency's Cancer Assessment Group (CAG, 1985). For chronic exposures to chemicals not known to produce carcinogenic effects, Acceptable Daily Intake (ADI) values were adopted from the values published by various program offices of the United States Environmental Protection Agency (USEPA, 1984b). In the absence of published values, ADI values were estimated from animal data using the methodology described earlier in this chapter (see page 16).

Acute exposures were evaluated in terms of the dose or concentration resulting in no effect as well as the dose or concentration resulting in no adverse effect on an exposed human population. For exposures by inhalation, consideration was given not only to the importance of chemical concentration, but also to the time dependence of toxicity.

RISK CHARACTERIZATION

Risk characterization of the releases from the OWMC facility was undertaken separately for (1) chronic exposure to carcinogens; (2) chronic exposure to non-carcinogens; and (3) acute exposures. In making the distinction betwen carcinogens and non-carcinogens, consideration was given to the particular route of exposure, since some chemicals, e.g., formaldehyde, may be carcinogenic by inhalation and not by ingestion. Chronic risk was characterized for carcinogens by multiplication of the calculated daily human dose (DHD) by the unit cancer risk (UCR). We note that the cancer risks presented here are for incidence of cancer which should not be considered equivalent to death.

$$\text{Cancer Risk} = (\text{UCR})\ (\text{DHD})$$

These numbers were then summed for all the carcinogens of concern and a total cancer risk for a particular pathway was derived. Total cancer risks for fugitive and incinerator emissions were calculated separately.

Non-carcinogenic risks were treated in a different manner. Non-carcinogenic risk for chronic exposures was obtained by dividing the Acceptable Daily Intake (ADI) for the chemical by the calculated daily human dose (DHD) in order to obtain an adjusted margin of safety (AMOS).

$$\text{Adjusted Margin of Safety (AMOS)} = \frac{\text{ADI}}{\text{DHD}}$$

The adjusted margin of safety developed for this study differs from the margin of safety described previously (see page 18) by incorporating a safety factor to derive the ADI from the No-observed-adverse-effect-level (NOAEL) for chronic exposure, i.e., ADI = NOAEL/Safety Factor. The AMOS values derived in this way were then grouped and aggregated for each organ of the body affected using the following formula:

$$\text{Aggregated AMOS} = (\Sigma 1/\text{AMOS})^{-1}$$

where Σ represents the sum of all $\frac{1}{\text{AMOS}}$ values for the same organ.

For example, all liver toxin risks were aggregated in this way. This allowed an estimation of the daily burden placed on an organ due to exposure from several chemicals.

These aggregation methodologies are consistent with guidelines for health risk assessment for chemical mixtures recently proposed by the United States Environmental Protection Agency (USEPA, 1985). In the absence of data to the contrary, the USEPA has suggested that risks from exposure to mixtures of chemicals be estimated as though their effects were additive. This approach is considered to provide a reasonable estimate of risk for the purposes of the generic risk assessment.

For acute exposures, the characterization of risk was conducted in a similar manner. In this case, however, an acute NOEL to which a safety factor had been applied was used (instead of an ADI) for comparison to the human dose (HD) received over a short time period.

$$\text{Adjusted Margin of Safety (AMOS)} = \frac{\text{(NOEL)}}{\text{(HD) (Safety Factor)}}$$

In some cases, depending upon the toxicological action of the chemical, it was more appropriate to make a comparison between a predicted concentration and a NOEL based on concentration rather than dose.

It should be emphasized that the use of a NOEL rather than a NOAEL in the characterization of acute risks represents a highly conservative approach. For short term exposures that occur relatively infrequently, a more conventional approach would be to base an acceptable level on the possible occurrence of minor, reversible and nonincapacitating effects (NRC, 1979). The more conservative approach to estimating AMOS values, however, was adopted as being consistent with the use of conservative assumptions throughout the risk assesment and OWMC's goal of minimizing risk to human health.

In assessing the risks resulting from the predicted exposures, it was necessary to evaluate the significance of the calculated AMOS values and cancer risks. For non-carcinogenic risks, exposure events that led to AMOS values of one or greater were considered not to pose any public health risk. In such cases, the ADI for chronic exposures, or the NOEL to which an appropriate safety factor had been applied for acute exposures, were greater than the predicted dose. Thus, the level of exposure was considered below that sufficient to cause an adverse health effect.

If the AMOS value was less than one, this result was interpreted differently for chronic and acute exposures. For chronic exposures, if the AMOS value was less than one, the predicted exposure was considered significant and so was the potential for human health effects.

For acute exposures, if the AMOS value was less than one, this was considered an indicator of a potential effect but not necessarily an adverse health effect, because of the use of the NOEL rather than NOAEL. In such cases, the potential for an adverse health effect was evaluated further using the criteria developed by the National Academy of Sciences (NRC, 1979) for short term exposure limits for air pollutants (see page 19). Using these criteria, the National Academy of Sciences (NAS) has currently put forward two types of short term exposure limits: short term public limits (STPLs), and emergency exposure limts (EELs)[2]. The short term public limits (STPLs) relate to predictable single exposures, usually lasting 60 minutes or less, but never more than 24 hours. If not

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[2]A third limit, termed the short term public emergency limit, was developed by NAS initially, but is not particularly useful in this context.

exceeded, the STPLs are expected to be associated with, at most, nonincapacitating, reversible effects. They differ from the emergency exposure limits (EELs) in that the EELs were (1) developed initially for defined occupational groups, e.g., military personnel; (2) relate to unpredictable single exposures; and (3) reflect the likely occurrence of nonincapacitating, reversible effects while avoiding any significant decrement in motor performance during emergencies. The STPLs were considered more applicable to the objectives of the CWMC risk assessment and were used, therefore, to assess the potential for acute health effects in cases where the AMOS values were less than one.

For carcinogens, the potential for public health risk was evaluated using a different format. For each risk pathway, a quantitative carcinogenic risk was calculated and the level of risk was evaluated against some level of acceptable risk. For the purposes of this risk assessment, a value of one in a million additional cancers over a lifetime of exposure was considered as the criterion for acceptable cancer risk. The use of this value finds precedent in the regulation of toxic chemical exposures in other situations.

For example, the United States Food and Drug Administration (USFDA), in its regulation of carcinogenic animal feed additives, established an acceptable residue level in the tissues of animals going to slaughter equal to or less than that level, which over a lifetime of exposure, would lead to an increased risk of one in a million additional cancers. Thus, the USFDA chose the one in a million risk level as a proper balance between the benefits derived from using carcinogenic animal feed additives

and the potential public health risk that results from the consumption of residual levels of these contaminants in the food supply (USFDA, 1979).

Other risk values have also been used by governmental agencies in the United States in their efforts to regulate human exposure to carcinogenic agents. In establishing water quality criteria, the United States Environmental Protection Agency (USEPA) acknowledged the fact that, to insure the maximum protection of public health, no exposure to chemical carcinogens would be desirable. However, such an exposure limit is unobtainable and, therefore, the Agency derived quantitative estimates of cancer risk that could result from exposure to the chemicals of concern and expressed a range of risk estimates from 10^{-5} to 10^{-7} (USEPA, 1980). Similarly, in its proposed guidance for establishing alternate concentration limits (ACL)[3] for hazardous constituents in groundwater at hazardous waste sites, consideration is given to setting acceptable risk levels: "In general, the Agency has made decisions to allow concentrations of carcinogens where the individual risk values have been within the range 10^{-4} to 10^{-8}" (USEPA, 1984). The guidance recommends "that [RCRA] permit writers encourage owners and operators [of hazardous waste management facilities] to consider a level of 10^{-6}, the middle of the range, to be used as the point of departure when proposing a risk level within the 10^{-4} to 10^{-8} range for their particular facility."

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[3]Hazardous waste regulations promulgated under the United States Resource Conservation and Recovery Act require that concentrations of hazardous constituents in groundwater measured at the edge of the waste management area do not exceed background levels. Alternate concentration limits (ACLs) can be established based on demonstration of no potential effects on human health and the environment.

Based on the above examples, the choice of a value of one in a million additional cancers over a lifetime of exposure was considered conservative and appropriate for the present analysis.

CHAPTER 3

CHARACTERIZATION OF RELEASES

3.1 CHARACTERISTICS OF FACILITY

The proposed OWMC facility will consist of the following major components:

- Waste handling and storage
- Incinerator plant
- Physical/chemical treatment plant
- Solidification plant
- Engineered landfill.

Also included here as part of the waste management system that can potentially result in environmental releases is the transportation of hazardous wastes to the facility, even though the transport vehicles are not planned to be operated by OWMC.

These components and the associated transportation system will be designed for an initial capacity of 150 000 metric tons per annum (t/a), which would include capacity for the treatment of 120 000 t/a of inorganic wastes, and the incineration of 30 000 t/a of organic wastes. Provisions have been made in the current design work for expansion of the total facility to an ultimate capacity of 300 000 t/a should this be necessary. For purposes of characterizing releases from the facility, it was

conservatively assumed that the facility will operate at the upper capacity limit of 300 000 t/a.

Each of the components of the OWMC facility is described in detail in the Status Report - Facility Design prepared by the engineering consultants (Monenco, 1985a).

WASTE ARRIVAL AT FACILITY

It is expected that all wastes will arrive at the facility in trucks of various types and sizes ranging from pick-ups to large multi-axle vehicles. Wastes generally will be containerized in three ways: drums or other types of containers; dump trucks or luggers; and tankers (tank trucks or tank trailers).

WASTE HANDLING AND STORAGE

Prior to appropriate treatment and disposal at the facility, all wastes first will be sampled for analysis and then transferred to intermediate storage facilities. The precise nature of the handling steps involved will depend upon the physical and chemical characteristics of each waste and the container type in which the waste is received.

INCINERATOR PLANT

A rotary kiln incinerator will be used to destroy organic wastes at high temperatures. At the maximum planned capacity of the facility (300 000 t/a), two separate incinerator units are envisioned. Combustion gas from the incinerator(s) will be cleaned by a flue gas treatment system which will not generate any liquid effluent discharge.

PHYSICAL/CHEMICAL TREATMENT PLANT

A physical/chemical treatment plant will be used to treat inorganic wastes and remove contaminants using proven physical and chemical processes. The physical/chemical treatment plant will also be used to recover oils from selected aqueous organic wastes using physical/chemical processes; recovered oils will be sent to the incinerator plant for destruction.

SOLIDIFICATION PLANT

The solidification plant will use cement and other reagents and additives. These will be mixed with the residues of incineration and physical/chemical treatment to immobilize the contaminants in a solid mass. This solid mass will be disposed of in an engineered landfill.

ENGINEERED LANDFILL

The engineered landfill will be used to contain the solidified residues in an environmentally safe manner using appropriate design and operating procedures. No untreated waste will be deposited in the landfill. Leachate generated in the landfill will be collected and analyzed, and will be treated if necessary.

3.2 MAJOR SOURCES OF RELEASES

In characterizing environmental releases associated with the facility operations, four sets of conditions were considered: (1) normal operating conditions, (2) upset conditions, (3) on-site accidents, and (4) off-site transportation accidents. Based on a review of the facility design and operating procedures, the principal sources of environmental releases were

identified as waste handling and storage, incineration, physical/chemical treatment, and transportation accidents. The sources of air emissions and the chemicals of concern associated with these emissions are summarized in Table 5. Each class of environmental releases is described briefly below.

NORMAL OPERATING CONDITIONS

The OWMC facility has been designed to minimize releases of toxic pollutants. Under normal operating conditions, however, routine emissions will be associated with waste handling and storage, physical/chemical treatment and incinerator operation.

Waste handling and storage and physical/chemical treatment, give rise to fugitive emissions, including volatile organic chemicals. These emissions are generated as residual emissions from pollution control devices and from miscellaneous uncontrolled sources. The following sources of fugitive emissions were identified for the OWMC facility and are described in greater detail in the engineering consultants' report entitled Site Selection Process. Phase 4A: Selection of Preferred Site(s) - Engineering (Monenco, 1985b):

- Waste unloading and transfer
- Drum opening
- Drum transfer
- Storage tanks
- Dissolved air flotation (DAF) unit
- Emulsion breaking
- Routine spillage.

TABLE 5

SOURCES OF ENVIRONMENTAL RELEASES

Facility Operation	Source of Release	Chemicals of Concern
A. NORMAL OPERATING CONDITIONS		
1. Waste Handling and Storage	Fugitive Emissions	Volatile organics
2. Physical/Chemical Treatment	Fugitive Emissions	Volatile organics
3. Incinerator	Stack Emissions	Organics, toxic by-products, metals and acid gases
B. UPSET CONDITIONS		
1. Incinerator	Scrubber Failure	Acid gases
C. ON-SITE ACCIDENTS		
1. Waste Handling and Storage	Mixing of incompatible wastes	Hydrogen sulfide
	Tank farm fire	Volatile organics
D. OFF-SITE ACCIDENTS		
1. Transportation	Accidental spill	Volatile organics

For the incinerator operations, air pollutants may be generated from a number of sources: organic chemicals present in the waste feed, acid gases generated in the combustion process, metals present in the waste feed, and products of incomplete combustion. These products of incomplete combustion (PICs) are formed as a result of partial oxidation of chemicals in the waste feed due to the combination of molecular fragments outside the combustion zone. At present there is limited information on the mechanism by which these PICs are formed, and how their formation can be related to waste feed or incinerator operating conditions (see ORF, 1985a). In the absence of such information, consideration was given to a particular set of possible PICs: the dioxins and furans. While there is considerable uncertainty about the formation of dioxins and furans in the incineration of hazardous wastes, their presence has been detected in low concentrations in the exhaust gases from some hazardous waste incinerators (see ORF, 1985a; Monenco, 1985a; Oberg, 1984; Radian, 1984). Because of the particular concern with the toxicity of these compounds, dioxin emissions were included in the risk assessment.

FACILITY UPSET CONDITIONS

At any industrial facility, the potential exists for equipment failure or operator error to result in upset conditions. At this preliminary stage in the design of the facility, a detailed hazard analysis of potential upset conditions has not been undertaken. It is recommended that such a hazard analysis be included in the next stage of the Facilities Development Process to facilitate site specific risk assessment. Based on the current design concepts, a number of potential upset conditions have

been identified by the engineering consultants (see Monenco, 1985b). These include failure of the carbon adsorption system used to control air emissions from the waste handling and storage units; failure of the incinerator scrubber which removes acid gases; and pH excursions during the treatment of cyanide wastes or in the precipitation of metals using sulfide. Emissions associated with failure of the carbon adsorption system and pH excursions were considered of minor significance relative to the other emissions, and were not addressed further in the risk assessment.

ON-SITE ACCIDENTS

As is the case for facility upset conditions, there is the potential for on-site accidents which can generate releases of hazardous constituents. It is possible to envision a wide range of such accident scenarios with different severities and probabilities. Consistent with the philosophy of adopting conservative assumptions throughout the risk assessment, the analysis of on-site accidents was focused on occurrences that would result in relatively severe consequences.

As is the case for facility upset conditions, a detailed hazard analysis of the facility has not yet been undertaken. However, based on the current design, the most severe accidents identified by the engineering consultants (see M.M. Dillon, 1984; M.M. Dillon, 1985a; Monenco, 1985b) were: (1) the mixing of incompatible wastes with subsequent generation of hydrogen sulfide gas; and (2) a fire in the organic waste tank farm resulting in the boiling of a tank containing solvent wastes.

OFF-SITE TRANSPORTATION ACCIDENTS

Transportation accidents can occur on the access routes to the OWMC facility. For the purposes of the risk assessment, a traffic accident was envisioned whereby a tank truck containing volatile organic wastes spills its entire contents on the access route to the facility. Spills involving smaller releases may occur more frequently, either from traffic accidents or as a result of equipment failure. Again, consistent with the philosophy of adopting conservative assumptions throughout the risk assessment, a scenario involving total loss of contents was selected for analysis.

3.3 SELECTION OF SURROGATE CHEMICALS

For the environmental releases under normal operating conditions, there is a multiplicity of different chemicals which may be released depending upon the waste feeds in any given time period. Similarly, for the episodic releases that occur as a result of upsets and accidents, the precise nature of the chemical released will depend upon the particular waste stream being handled at the time and location of the incident. To model quantitatively the release of all such chemicals clearly would not be a feasible task. The approach adopted, therefore, was to select a manageable number of surrogate chemicals that represent the most hazardous chemicals to be handled at the facility. This approach is consistent with the conservative philosophy adopted throughout the risk assessment process.

The starting point for the selection of surrogate chemicals was the waste characterization data base which has been developed to estimate the types and quantities of special wastes generated in Ontario (Canviro, 1985). This waste inventory has been categorized using the University of California at Davis (UCD) classification scheme, whereby waste streams are grouped in UCD categories according to similarities in chemical constituents and physical state (see OWMC, 1982). Each UCD category can contain many different waste streams. These UCD categories are further organized into broader waste classes based on generic similarities.

To select surrogate chemicals for the various types of environmental releases, a series of ranking schemes was developed. For the long-term releases, i.e., releases under normal operating conditions, the objective of the ranking scheme was to identify the most hazardous chemical within a particular UCD category and, thus, to generate a list of surrogates representing all UCD categories. For the short-term releases, i.e., releases associated with upset conditions and accidents, the objective of the ranking scheme was to identify the most hazardous chemical that could be released in a particular incident. Each ranking scheme generated a hazard index as an indicator of the degree of hazard of a waste stream. The hazard indices were based on parameters specific to each source of release and are summarized in Table 6. Additional details of the ranking schemes used in the surrogate selection process are provided in Appendix B (see Volume 2 of this report).

TABLE 6

SELECTION OF SURROGATE CHEMICALS

Facility Operation	Source of Release	Selection Parameters
A. NORMAL OPERATING CONDITIONS		
1. Waste Handling and Storage	Fugitive Emissions	Chronic toxicity, chemical quantity, vapor pressure
2. Physical/Chemical Treatment	Fugitive Emissions	Chronic toxicity, chemical quantity, vapor pressure
3. Incinerator	Stack Emissions	Chronic toxicity, chemical quantity[1]
B. UPSET CONDITIONS		
1. Incinerator	Scrubber Failure	Not applicable[2]
C. ON-SITE ACCIDENTS		
1. Waste Handling and Storage	Mixing of incompatible wastes	Not applicable[3]
	Tank farm fire	Acute toxicity, chemical quantity, heat of vaporization
D. OFF-SITE ACCIDENTS		
1. Transportation	Accidental spill	Acute toxicity, chemical quantity, vapor pressure

Notes:

[1]Selection parameters for incinerator stack emissions under normal operating conditions apply only to volatile organics. Acid gases, metals and dioxins/furans selected from review of empirical data.

[2]Acid gases defined as contaminants of concern by upset condition.

[3]Generation of hydrogen sulfide selected as event of greatest concern in previous study (M.M. Dillon, 1984).

We note that in several cases a surrogate selection scheme was not applied since the surrogates were essentially "preselected". For example, in the case of incinerator emissions, the acid gases, metals and dioxins/furans were preselected by review of empirical data. Similarly, in the case of mixing of incompatible wastes, the use of hydrogen sulfide was determined by the event chosen in earlier work for OWMC on the selection of a technical buffer zone (M.M. Dillon, 1984), which was subsequently incorporated by the engineering consultants (Monenco, 1985b).

For the release types to which the surrogate selection schemes were applied, each hazard index was based on three factors: the inherent hazard of the chemical; the potential for the chemical to be released to the environment; and the quantity of chemical available for release. In the case of releases under normal operating conditions, risk to human health is based on long term exposure, so that the chronic toxicity was used to define the inherent hazard. For accidents and upset conditions, acute toxicity was considered a more appropriate measure of inherent hazard because of the short term nature of the exposures.

The definition of release potential was based on a parameter describing the tendency of the chemical to escape into the atmosphere. For transportation spills and fugitive emissions associated with waste handling and storage, the parameter selected was vapor pressure; for the tank farm fire, heat of vaporization provided a measure of the energy required to vaporize the chemical; and for incineration, the

chemicals were assumed to behave essentially uniformly under high temperature conditions, so no differentiation of their release potential was included.

The quantity of chemical was based on the concentration data and estimates of waste quantities developed from the Canviro data base (see Canviro, 1985).

3.4 ESTIMATION OF RELEASE RATES

Release rates for the selected surrogate chemicals were estimated using a combination of empirical data from comparable facilities (ORF, 1985a) and by engineering calculations (Monenco, 1985b). The methodology and data base for each major source of release are outlined below. A more detailed description of the methodology and a summary of the release rates for each surrogate chemical are presented in Appendix C (see Volume 2 of this report).

FUGITIVE EMISSIONS

Fugitive emissions of volatile organic compounds were estimated using engineering calculations developed by the engineering consultants (Monenco, 1985b). Data inputs to these calculations were based on the current design of the facility (Monenco, 1985a) and the available information on waste characteristics, primarily from the Canviro data base (Canviro, 1985). Attention was focused on those waste classes which were considered most likely to contain significant concentrations of volatile organics, specifically:

Class 1	Organic sludges and still bottoms
Class 2	Solvent and organic solutions
Class 3	Oils and greases
Class 4	Oil and water mixtures
Class 5	Organic and oil residuals
Class 7	Miscellaneous chemicals and products
Class 8	Paint and organic residuals
Class 9	Aqueous solutions with organics
Class 12	Pesticide and herbicide wastes
Class 13	PCB wastes
Class 14	Cleanup residuals

In the case of oily wastes (Class 4) treated in the physical/chemical treatment plant, data on volatile organic compounds in these wastes were not available in the Canviro data base. For these wastes, the concentrations of volatile organics were based on a data base developed in the United States for waste oils (Franklin Associates, 1983).

In calculating the emission rates, it was conservatively assumed that all wastes go through each of the handling and storage and treatment operations identified as emission sources, with the exception of PCB wastes. PCB wastes in bulk will be pumped directly from arriving tank trucks to storage tanks, without intermediate handling in the reception basins, so that there will be no PCB emissions from the reception basins.

INCINERATOR STACK EMISSIONS

Incinerator stack emissions of organic chemicals were based on a 99.99% destruction and removal efficiency for the surrogate chemicals in the waste feeds. Concentrations of surrogate chemicals in the waste feeds were based on the available information on waste characteristics in the Canviro data base (Canviro, 1985). Other emissions, i.e., metals, acid gases and dioxins/furans were based on empirical data compiled by ORF (1985a).

INCINERATOR SCRUBBER FAILURE

In the event of a flue gas scrubber failure due to a power failure, the facility design and emergency procedures provide for shutdown of feed to the incinerator immediately and emergency power to resume the supply of water to the scrubber in less than two minutes (Monenco, 1985b). The emergency water supply from a head tank would meet the gas quenching requirements within the two minute period, and would also provide partial scrubbing of the gas. Gas flow would decrease to about 10% of normal in four minutes. After two minutes, the concentration of contaminants in the emitted gas would be as normal, and the gas flow would continue to fall to 10% of normal. For estimating the emission rate under these conditions, it was conservatively assumed that power failure could result in scrubber failure for both incinerator units.

MIXING OF INCOMPATIBLE WASTES

Emissions of hydrogen sulfide gas as a result of incompatible waste mixing were based on a scenario developed in earlier work for OWMC on the selection of a technical buffer zone (M.M. Dillon, 1984) which was adopted

subsequently by the engineering consultants (Monenco, 1985b). This scenario assumes that "operational and engineering controls would prevent the gross contamination of sulfide wastes with strong acids, and that the worst probable occurrence would be the accidental addition of a barrel of strong acid to sulfide wastes or vice versa". The accident case analyzed assumed that one 55 gallon drum of 4% sulfuric acid was mixed with sulfide wastes in the physical/chemical treatment plant building. The gas would be emitted first into the building and then via its ventilation system to the atmosphere at roof level.

TANK FARM FIRE

Tank farm fire emissions were also based on a conservative scenario developed in earlier work for OWMC in the selection of a buffer zone (M.M. Dillon, 1984), which subsequently was adopted by the engineering consultants (Monenco, 1985b). In this scenario it is envisioned that a 2500 gallon tank full of the selected surrogate chemical is exposed to a fire surrounding the tank. The contents of the tank are boiled off through the tank's pressure relief valve, and vented above the level of flame effect. Assuming that the tanks are uninsulated, the rate of boil-off, or the emission rate, was estimated by the method of the American Petroleum Institute (API, 1976) as:

$$Q = \frac{(21\,000)\ (F)\ (Aw)^{0.82}}{\Delta H}$$

where Q = emission rate, lb/h

F = insulation factor = 1.0 for a bare vessel

Aw = wetted surface area of tank, ft^2

ΔH = heat of vaporization, Btu/lb

For the purposes of the risk assessment, the scenario was modified (based on the results of the surrogate selection scheme which showed that methylene chloride was more hazardous than 1,1,1-trichloroethane) to use methylene chloride as the surrogate chemical instead of 1,1,1-trichloroethane used in the original scenario.

TRANSPORTATION SPILL

The transportation spill scenario assumes that a 30 tonne tank truck carrying a load of liquid waste is involved in a collision on the local access road, resulting in tank rupture and release of the entire contents of the truck. The released liquid spreads across the road surface to form a pool from which the selected surrogate chemical, methylene chloride, is released to the atmosphere. Clearly, different circumstances prevailing at the time of the spill (e.g., nature of the tank rupture, configuration of road surface, shoulder or roadside ditches) will affect the behavior of the liquid pool. As a conservative representation of pool size, the geometry of the pool was assumed to be circular with the center of the circle coincident with the centerline of the road, and the diameter constrained by the width of the paved surface of the road (7.0 m). The emission rate was then based on the equation of Stiver and Mackay (1982):

$$Q = \frac{(K_g)\ (A)\ (P)\ (M)}{(R)\ (T)}$$

where Q = emission rate, g/s

K_g = the gas mass transfer coefficient, m/s

A = area of spill, m^2

P = vapor pressure of the chemical or mixture, Pa

M = molecular weight of compound, g/mole

R = gas constant, Pa m^3/mole °K

T = temperature, °K

The derivation of the gas mass transfer coefficient and adaptation of the emission equation to address mixtures of compounds are presented in Appendix D (see Volume 2 of this report).

The emission rate is sensitive to environmental parameters, specifically wind speed, which affects the mass transfer coefficient (K_g) and ambient temperature. For example, the emission rate at 0°C will be approximately three times lower than at 30°C. For the purposes of the risk assessment, emission rates were estimated conservatively by using a temperature of 25°C, considered typical of average summertime temperatures in Southern Ontario. A wind speed of 1 m/s was used to correspond to the atmospheric stability class F subsequently used to model atmospheric transport (see Gartner Lee Associates Limited, 1982 for discussion of atmospheric stability classes).

CHAPTER 4

DIRECT EXPOSURES TO FACILITY EMISSIONS

4.1 PATHWAY DEFINITION

Direct exposures to facility emissions can be divided into two groupings: (1) long term exposures to emissions associated with normal facility operating conditions; and (2) short term exposures associated with facility upset conditions and accidents. For purposes of the risk assessment, it was assumed that human exposure occurs continuously over the maximum time period plausible, i.e., over a possible 30-year life of the facility for long term emissions and for the actual duration of episodic emissions.[4] Moreover, consistent with the conservative approach used throughout the risk assessment, it was assumed that an exposed individual is located permanently at the point of maximum concentration. The location of this point will be different for different emission types, depending largely upon the height of the emission source. In the case of incinerator stack emissions, this location will be the point of impingement located about two kilometres from the facility. For emissions which are vented from the physical-chemical treatment plant, under upset conditions, the point of impingement will be located

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[4]As indicated previously (see page 25), a 30 year operating period was selected as a more conservative representation of the operating life than the 20-year period used in other Phase 4A site selection studies.

approximately 300 m beyond the perimeter of the facility buffer zone. At distances either closer or further from the point of impingement, pollutant concentrations will be lower and human exposures will be correspondingly reduced.

For other emissions occurring at ground level or close to ground level, e.g., fugitive emissions, the maximum concentration for off-site receptors will occur at a point on the perimeter of the facility buffer zone. For these emissions, pollutant concentrations will be lower at distances beyond the perimeter of the facility buffer zone, and human exposures also will be correspondingly reduced. The methodology for assessing these human exposures and characterizing risk is described in the following sections.

4.2 LONG TERM EXPOSURES

To predict human exposures, the ambient concentration levels were modeled using a Gaussian dispersion plume model. Modeling of average annual concentrations was carried out using the United States Environmental Protection Agency's Industrial Source Complex model (see ORF, 1985b for discussion of this model). This Gaussian model calculates concentrations at an array of receptors for a complete range of meteorological parameters, and the results are weighted according to the frequency of occurrence of these parameters over the year. Meteorological conditions typical of both the Halton/Peel and Niagara regions were used initially as inputs to the model. Since the predicted concentrations were consistently higher for the Niagara region, these conditions were used for the exposure

assessment. Incinerator stack emissions were modeled assuming a 60 m stack height. Fugitive emissions were considered in two groupings: those emitted at ground level or close to ground level, and those vented from the roof of the physical-chemical treatment building at a height of 25 m.

In applying the dispersion models, different time-averaging periods were used for emissions of carcinogenic and non-carcinogenic chemicals. For carcinogens, the total lifetime dose is the determining factor in defining risk, so that maximum annual concentrations were used to estimate human exposure. For non-carcinogens, it was conservatively assumed that the maximum average concentration over a two week period represents chronic exposure. Using these assumptions, the dispersion factors expressed as the estimated maximum annual and maximum two-weekly ambient concentrations for a unit emission rate are presented in Table 7.

TABLE 7

ESTIMATED DISPERSION FACTORS
FOR LONG TERM EMISSIONS

Emission Source	Maximum Annual Concentration $(ug/m^3)/(g/s)$	Maximum Two-Week Concentration $(ug/m^3)/(g/s)$
Incinerator Stack Emissions	0.036	0.3
Fugitive Emissions (Ground level)	23.5	120
Fugitive Emissions (25 m)	1.93	8

Source: Ontario Research Foundation

From the estimated ambient concentrations, a daily human dose (DHD) was calculated using the following equation:

$$DHD = \frac{(E_n)(D_f)(BR)(AF)}{BW}$$

where DHD = daily human dose, mg/kg/d

E_n = emission rate for chemical n, g/s

D_f = dispersion factor, $(mg/m^3)/(g/s)$ [see Table 7]

BR = breathing rate, m^3/h [see Table 4]

BW = body weight, kg [see Table 4]

AF = absorption factor, dimensionless

Human health risks were then estimated using the methodologies for carcinogens and non-carcinogens described in Chapter 2. For carcinogens, the measure of health risk for each chemical was the cancer risk, given by:

$$\text{Cancer risk} = (UCR)(DHD)$$

where UCR = unit cancer risk, $(mg/kg/d)^{-1}$

For the non-carcinogens, the measure of health risk was the adjusted margin of safety for each organ of concern, given by:

$$AMOS = \frac{ADI}{DHD}$$

where ADI = acceptable daily intake, mg/kg/d

For each of the non-carcinogens, the AMOS values were all greater than one, thus predicting that an adverse health effect would not be experienced at these exposure levels. The effects of non-carcinogens were

therefore not considered further. For carcinogens, since there is no threshold below which a prediction of "no adverse health effect" can be made, cancer risks were aggregated for all carcinogens. The estimated cancer risks for fugitive and incinerator stack emissions were 1×10^{-6} and 9×10^{-7} respectively. In both cases, the risks are of a magnitude which should not be considered a significant human health hazard.

4.3 SHORT TERM EXPOSURES

To predict short term exposures, the ambient concentrations were modeled using a Gaussian dispersion plume model (see ORF, 1985b for discussion of this model). A short term model was used to establish concentrations for ground based inversions in the case of ground level emissions, and for fumigation conditions in the case of stack emissions. These were considered "worst-case" meteorological conditions. The height of the emission point was modeled for each emission source as follows: incinerator scrubber failure was modeled for a 60 m stack height; the tank farm fire was modeled as a ground level emission; and the mixing of incompatible wastes was modeled for a vent on the roof of the physical-chemical treatment building at a height of 25 m.

In applying the dispersion models, different time-averaging periods were used to represent acute exposures depending upon the duration of the emission. The maximum half-hour average concentrations were used to represent acute exposures for the tank farm fire and mixing of incompatible wastes. In the case of the incinerator scrubber failure, the emission can be considered as a release of short duration. As a

conservative approach, the release was modeled as a continuous release of two minute duration. This two-minute period was considered to approximate the maximum exposure time for a receptor at the point of maximum concentration. Using these assumptions, the dispersion factors expressed as the estimated maximum half-hour and maximum two-minute ambient concentrations for a unit emission rate are presented in Table 8.

TABLE 8

DISPERSION FACTORS FOR

SHORT TERM EMISSIONS FROM FACILITY UPSETS

Emission Source	Maximum Half-Hour Concentration $(ug/m^3)/(g/s)$	Maximum Two-Minute Concentration $(ug/m^3)/(g/s)$
Incinerator Scrubber Failure	24	38
Tank Farm Fire	3550	Not applicable
Mixing of Incompatible Wastes	160	Not applicable

Source: Ontario Research Foundation

For both the incinerator scrubber failure and incompatible waste mixing, health risk was evaluated by comparing the predicted concentrations to a concentration-based NOEL. For the tank farm fire human dose for the actual period of exposure was calculated using the following equation:

$$HD = \frac{(E_n)(D_f)(BR)(AF)(t)}{BW}$$

where HD = human dose, mg/kg

E_n = emission rate for chemical n, g/s

D_f = dispersion factor, $(mg/m^3)/(g/s)$ [see Table 8]

BR = breathing rate, m^3/h [see Table 4]

BW = body weight, kg [see Table 4]

AF = absorption factor, dimensionless

t = exposure time, h

Human health risks were then estimated as the adjusted margin of safety (AMOS) using the methodology described in Chapter 2:

$$AMOS = \frac{(NOEL)}{(HD)(Safety\ Factor)}$$

The AMOS values are presented in Table 9.

TABLE 9

RISK ESTIMATES FOR ACUTE EXPOSURES

Source of Release	Chemical of Concern	Duration of Exposure	AMOS
Tank Farm Fire	Methylene chloride	2.6 h	0.02
Mixing of Incompatible Wastes	Hydrogen sulfide	42 min	27
Incinerator Scrubber Failure	Sulfur dioxide	2 min	0.06
	Nitrogen oxides		2
	Hydrogen chloride		0.5
	Hydrogen fluoride		10

Notes: 1) Incinerator stack scrubber failure based on simultaneous failure of scrubbers on both incinerator units.
2) AMOS values presented for point of maximum concentration: perimeter of facility buffer zone for tank farm fire; approximately 300 m beyond facility buffer zone for mixing of incompatible wastes, and approximately 2 km from facility for incinerator scrubber failure.

For the tank farm fire and incinerator stack scrubber failure, AMOS values less than one were predicted. However, it should be recognized that, at this time, the possible mitigation of these events by modifications to the facility design or operations has not been included. It should be recognized also, that the derivation of the AMOS values for short term exposure relies on the use of conservative safety factors, which were developed to protect against any effect rather than adverse health effects (see page 29).

The significance of the AMOS value in terms of the potential for adverse health effects can be assessed further by application of the methodology that would be used conventionally in establishing short term limits for public exposure. This methodology was described in Chapter 2 of this report (see page 30), and generates short term public limits (STPLs) designed for predictable single exposures, usually lasting 60 minutes or less, but never more than 24 hours. The STPLs are limits that, if not exceeded, are expected to be associated with, at most, a nonincapacitating, reversible effect in an exposed population. A nonincapacitating, reversible effect is defined as one that will not cause a period of disability; will not impair one's vision, visibility, judgement, or ability to breathe; and will not interfere with one's ability to escape from the site of exposure. These STPLs are considered appropriate for assessing the infrequent short term exposures associated with a tank farm fire or incinerator scrubber failure. A discussion of the STPLs to each of these scenarios follows.

In the event that the scrubber of both incinerator units fails simultaneously, AMOS values of 0.5 and 0.06 are predicted for hydrogen chloride and sulfur dioxide respectively. For hydrogen chloride, the predicted ambient concentration is 3.5 ppm for a period of approximately two minutes. The National Academy of Sciences (NRC, 1971) has reviewed exposure data on hydrogen chloride and established guidelines for short term exposure of the public. They conclude that the chief effect of inhalation exposure to hydrogen chloride will be irritation of the moist mucous membranes of the upper respiratory tract. Prevention of the disagreeable and irritating odor of hydrogen chloride thus was used as the basis for establishing short term public exposure limits. They assumed that the level at which hydrogen chloride could be detected is between 1-10 ppm and that values greater than 5-10 ppm are disagreeable and irritating. Using this approach NAS established a series of STPLs for exposure periods from ten minutes to one hour. For the ten minute period, an STPL of 4 ppm was established. This level is marginally higher than the 3.5 ppm predicted value expected to persist for two minutes. However, since the magnitude of the irritating effects for hydrogen chloride is likely to be a function of both concentration and exposure time, no adverse health effects would be expected for a two minute exposure period. The only effects likely to occur would be slight odors or minor, reversible irritation effects experienced by sensitive members of the population.

For sulfur dioxide the predicted ambient concentration is 1.7 ppm for a period of approximately two minutes. The effects of sulfur dioxide exposure are similar to those for hydrogen chloride, in that it acts as an

irritant to the mucous membranes of the respiratory tract and the conjunctiva of the eye. The National Academy of Sciences (NRC, 1984) reviewed the data available on sulfur dioxide exposure and established emergency exposure limits (EELs) for sulfur dioxide (but not STPLs). The EELs were established for defined occupational groups such as military personnel or space personnel, rather than the general public. They differ from the STPLs in the acceptance of a nonincapacitating decrement in performance during emergencies. The EELs established by NAS are for exposure periods from 10 minutes to 24 hours. For the 10 minute period, which is most applicable to the two minute scrubber failure scenario, an EEL of 30 ppm was established. To allow for the potentially greater sensitivity of individual members of the exposed population, e.g., asthmatics, and in order to define a no effect level, a short term public limit was derived for this study from the EEL by applying a ten-fold safety factor. This was considered to provide an adequate margin of protection for asthmatics and other respiratory compromised individuals. The derived STPL of 3 ppm is higher than the 1.7 ppm predicted value expected to persist for two minutes. Since the magnitude of the irritating effects for sulfur dioxide is likely to be a function of both concentration and time, no adverse health effects would be expected for a two minute exposure period. For sensitive populations, however, it is possible that minor, reversible effects, e.g., temporary tightness of the chest, might be experienced.

In the case of the tank farm fire, the predicted dose at the point of maximum exposure is approximately 150 mg/kg and the AMOS value is 0.02. A short-term public limit (STPL) can be calculated for methylene chloride

using a methodology parallel to that described for hydrogen chloride and sulfur dioxide. Applying the criterion that exposure must result in, at most, reversible effects in the exposed population, "no effect on psychomotor and cognitive measures" was reported at a concentration of 1000 ppm for two hours. This can be compared to a chronic 8 hour per day Threshold Limit Value (TLV) of 100 ppm and a Short Term Exposure Limit (STEL) of 500 ppm for occupational exposure (ACGIH, 1985). These data suggest that the STPL should be between 1000 ppm and 100 ppm. To allow for the potentially greater sensitivity of individual members of the public, an STPL was derived, therefore, by applying a five-fold safety factor to the 1000 ppm two-hour exposure. Using the assumptions for estimating human dose described in Table 3 (see page 23), an STPL of 17 mg/kg was estimated.

This is still significantly less than the predicted dose of 150 mg/kg. Therefore, while the biological impact on which the AMOS is based is extremely mild (i.e., changes in auditory threshold response), at the predicted exposure levels potentially significant health effects would be experienced. It is difficult to estimate how severe these effects would be, since human data for acute exposures to methylene chloride are generally for levels lower than this. For example, various studies cited in the literature for estimated doses in the range 22 to 67 mg/kg report effects such as lightheadedness, difficulty with speech, motor decrements and decreased eye and hand coordination (USEPA, 1983). However, the lowest reported dose at which a human fatality has occurred is 500 mg/kg. It can be concluded, therefore, that potentially severe effects would be

experienced for exposures to methylene chloride at the predicted level, although these are likely to stop short of death or incapacitating illness.

It should be recognized in reviewing the predicted health effects associated with episodic events that their frequency of occurrence may be relatively low. Comprehensive data are not available at this time to provide a rigorous analysis of the frequency for the short term exposure scenarios. Review of data from other comparable facilities, however, suggests that the tank farm fire, in particular, is a highly improbable event. For example, at the Kommunekemi Facility in Nyborg, Denmark, as of March 1983, the facility operators indicate that there have been only eight incidents in almost ten years of operation (Chemcontrol, 1983). One of these incidents involved an explosion and fire in a tank storing sludge destined for the incinerator. The fire was extinguished by Kommunekemi's fire brigade and reportedly no persons were injured. The fire was believed to have been caused by an accumulation of static electricity igniting a combustible vapor mixture within the tank. To eliminate the potential for this type of incident, tanks which could contain organic materials have been grounded to prevent buildup of static electricity, and an inert gas blanketing system has been installed to prevent the formation of a combustible vapor mixture. These same provisions will be incorporated into the design of the organic storage tanks at the OWMC facility.

CHAPTER 5

INDIRECT EXPOSURES TO FACILITY EMISSIONS

5.1 PATHWAY DEFINITIONS

In addition to the direct human exposure to facility emissions, the risk assessment also considered indirect exposure to toxic chemicals through the ingestion of food and water. Relevant exposure pathways included: ingestion of locally grown vegetables, consumption of beef and milk from locally raised cattle, and the use of cisterns and ponds for drinking water.

Specifically, the following pathways were examined based on long-term fugitive and incinerator stack emissions of metals and organic chemicals as characterized in Chapter 4:

- Ingestion of leafy vegetables exposed to emissions from the air, and chemical uptake from soil depositions;
- Ingestion of cistern and pond water exposed to emissions from the air;
- Ingestion of beef and milk from cattle ingesting exposed vegetation and water.

The methodology used to characterize human health risks associated with these indirect pathways is outlined in the following sections. A more detailed description of the environmental fate and transport processes considered is presented in Appendix D (see Volume 2 of this report).

5.2 INGESTION OF LEAFY VEGETABLES

In order to model human exposure due to the ingestion of exposed locally grown leafy vegetables, several simplifying assumptions were made. First, it was not possible to model exposure from all crops potentially grown in the vicinity of the proposed facility. This limitation, however, was not considered a significant shortcoming. Since all plants do not accumulate chemicals to the same extent and leafy vegetables are considered to accumulate chemicals to a greater degree than non-leafy vegetables, a hypothetical leafy vegetable was conceptualized for the exposure analysis.

Second, it was assumed that an individual's average daily intake of leafy vegetable was solely from this exposed vegetation source, and that this source represented a 30-year (facility lifetime) supply. This conservative assumption would overestimate chemical doses likely to occur.

Third, a five-month growing season was assumed. The amount of chemical deposited on leaf surfaces and taken up from the soil by the plant is directly influenced by the length of time the plant is in the field. A five-month growing season, or period in the field, is a conservative estimate for leafy vegetables and also would overestimate chemical doses likely to occur.

Estimation of the dose received from the ingestion of exposed leafy vegetables necessitates the calculation of the amount of chemical accumulated by the plant. Plants can accumulate chemicals in three major ways: by uptake from the soil through the root system, by uptake from the air through stomata, and by direct surface deposition. Of these three modes of accumulation, no information is available on plant uptake from the air for the organic chemicals of concern and this pathway was therefore omitted by necessity in the analysis. The two remaining routes differ in importance depending on the nature of the chemical. For example, deposition onto a leaf surface is a more important phenomenon for metals and non-volatile organic chemicals such as PCBs than it is for volatile organic chemicals, due to the tendency of volatile chemicals to partition into the air. The concentration or accumulation of a chemical by the plant can thus be broadly defined by three variables: an uptake factor, a surface deposition factor, and the deposition rate of the chemical from the emission of concern (Holton et. al., 1984):

$$C_p = d[A_d + U_p]$$

where: C_p = chemical concentration in the plant, ug chemical/kg plant

d = chemical deposition rate, ug/m^2 s

A_d = leaf surface deposition factor, m^2 s/kg

U_p = soil uptake factor, m^2 s/kg

The significance of these variables and methods for their estimation are summarized below.

CHEMICAL DEPOSITION RATE

Chemicals in the atmosphere can come into contact with soil and plant surfaces through wet and dry deposition processes. Dry deposition describes the contact of very small particles and gases in the atmosphere, with a surface, due to atmospheric turbulence and molecular motion. The wet deposition process describes the contact of chemicals in the atmosphere with a surface due to washout by precipitation. The deposition rate used to determine the concentration of pollutant in the plant was obtained from the sum of dry and wet deposition processes.

LEAF SURFACE DEPOSITION

Leaf surface deposition plays a significant role in plant accumulation depending on the fraction intercepted by vegetation, crop yield and various chemical specific surface degradation processes. The extent of surface coverage of the plant is determined by the interception fraction of the plant and the crop yield. Baes et al. (1984) have calculated a theoretical maximum interception fraction for leafy vegetables for a unit area based upon planting practices, relative importance of the crop (by area planted) and time in the field. This calculated maximum value was used in estimating leaf surface deposition. To allow for the effect of crop yield, which has the effect of "diluting" the pollutant concentration in the plant by lowering the surface deposition factor, data on crop yields in Ontario were obtained from Ecologistics for lettuce, cabbage, broccoli and cauliflower and combined for modeling of the hypothetical leafy vegetable.

For chemicals deposited on the surface of a leaf, two mechanisms for degradation were considered: volatilization and washoff by precipitation. For volatilization, only organic chemical volatilization was modeled; metals deposited onto leaf surfaces in the form of oxides or chlorides would not be lost through volatilization due to their extremely low vapor pressures. In the case of dioxin, no volatilization was assumed, since dioxin deposited onto a leaf surface may be strongly adsorbed to fly ash. This is a conservative assumption for a semivolatile chemical such as dioxin.

For precipitation, a weathering half-life of 15 days was assumed (Willis et al., 1980) for all the chemicals modeled from which a weathering rate constant was derived. This half-life was based on leaf washoff of the pesticide endrin, a highly hydrophobic chemical which would be expected to adsorb strongly to soil or leaf surfaces.

UPTAKE FROM THE SOIL

Chemicals deposited on the soil surface can leach into the soil solution in the root zone and be taken up by the plant. The extent of plant uptake was estimated using a plant-soil partition coefficient, with consideration also given to competing soil degradation processes. Plant soil partition coefficients are defined as the ratio of the concentration of chemical in the plant to the concentration of the chemical in the soil, at equilibrium.

The principal sources for estimating these coefficients were the microcosm studies of Figge et al. (1983) and food chain risk assessment work undertaken by the US Army Medical Bioengineering Research and Development Laboratory (Rosenblatt and Small, 1981). The highest

partition coefficient cited in these studies was conservatively selected for all chemicals in the risk assessment.

To allow for soil degradation processes, consideration was given to volatilization, leaching and biodegradation. Volatilization upward from the root zone through soil pores was estimated by the method of Bomberger et al. (1982). It was considered that such losses could be significant in removing chemicals of high volatility which do not adsorb onto soil particles. In the case of dioxin bound to fly ash, no volatilization was assumed.

Leaching from the soil depends on the amount of the precipitation, the soil porosity and the tendency of the chemical to resist migration by adsorption onto organic carbon found in the soil. This tendency is expressed by a partition coefficient (Koc), and describes the distribution of a chemical between soil organic carbon and water. It is therefore evident that soils with a large fraction of organic carbon will have a greater tendency to retain certain organic chemicals than soils with a low fraction of organic carbon. In order to calculate a leaching loss rate constant, it was assumed that the soils in question contain 1% organic carbon, which represents a typical soil organic carbon concentration (Gartner Lee Associates).

Biodegradation in soils is highly variable. Rate constants were obtained from the literature and where a range of values was indicated, the most conservative number (lowest rate of biodegradation) was selected. In the case of dioxin bound to fly ash, no biodegradation was assumed.

5.3 INGESTION OF BEEF AND MILK

The analysis of potential human exposure via ingestion of beef and milk was restricted to cattle since ruminants are good indicators of impacts on other species such as chickens and game. In order to assess the daily dose of chemical obtained from consuming contaminated beef and milk, it was first necessary to estimate the concentration of the chemical found in beef and milk due to leaf surface deposition and plant uptake. The model developed by Holton et al. (1984) was used to estimate this concentration by the use of cattle dietary assumptions, the concentration of chemical found in cattle food crops, and the fraction of chemical retained in beef and milk resulting from the consumption of exposed food crops:

$$C_i = (F_i)(Q_g)(C_g)$$

where C_i = the estimated concentration of the contaminant in milk or beef (ug/kg)

F_i = fraction of the contaminant consumed each day which is transported and retained in milk or beef (d/kg)

Q_g = the quantity of grains and grasses eaten by cattle each day (kg/d)

C_g = estimated concentration of contaminant in grains and grasses (ug/kg).

The fraction of chemical retained in cattle after consuming exposed grain, hay and corn silage (F_i) was estimated using correlation equations developed by Holton et al. (1984).

The concentration of the chemical in cattle food crops (C_g) was modeled in the same manner as for leafy vegetables (see Section 5.2). The diet of the cattle was considered to be comprised of corn silage, mixed grain and hay and the quantity consumed per day (Q) was provided by Ecologistics.

An additional assessment was performed to determine the contribution to human health risk from cattle drinking contaminated pond water as well as consuming contaminated grain, again using water consumption data provided by Ecologistics. The concentration of the chemical in the pond water was determined as discussed in Section 5.4.

5.4 INGESTION OF CISTERN AND POND WATER

The impact of fugitive and stack emissions on the quality of pond and cistern water was assessed as follows. For fugitive emissions, organic chemical contamination was considered; while both organic chemical and metal contamination were considered for stack emissions. For the purpose of this analysis, the effects of acid gases were considered to be negligible.

The chemical concentrations in water were conceptualized as being controlled by two different processes depending upon whether organic chemicals or metals are being considered.

The concentration of organic chemicals in pond and cistern water due to fugitive and stack air emissions was determined by Henry's Law (Lyman et al, 1982). Henry's Law describes how a gaseous chemical will distribute itself between air and water under ideal conditions:

$$C_A = (C_s)(H)$$

where C_A = equilibrium air concentration of the chemical above the dilute aqueous solution, g/cm^3

C_s = equilibrium aqueous concentration (dilute) of the chemical, g/cm^3

H = Henry's Law constant, dimensionless

Henry's Law cannot be used to estimate metal concentrations in pond and cistern water. This is because metals emitted from incinerators will not remain as a gas, but will quickly adsorb to fly ash or exist as solid oxides. For particles, therefore, concentrations must be estimated by the mass of material deposited into a volume of water.

Ponds in the vicinity of the candidate sites are typically 0.6 m to 7.6 m in depth (Gartner Lee Associates). The long term metal concentration in such a pond can be expressed as:

$$C_m = \frac{d}{P-E}$$

where C_m = concentration of metal in the pond, g/m^3

d = deposition rate, g/m^2 a

P = average annual precipitation, m/a

E = average annual evapotranspiration, m/a

This method is considered conservative since it does not take into account any dilution afforded by the initial contents of the pond.

5.5 EXPOSURE ASSESSMENT AND RISK CHARACTERIZATION

From the estimated ambient concentrations, a daily human dose was calculated using the following equations:

Leafy vegetables

$$DHD = \frac{(C_p)(Q_l)(AF)}{(BW)(1000)}$$

Milk

$$DHD = \frac{(C_i)(Q_c)(AF)}{(BW)(1000)}$$

Beef

$$DHD = \frac{(C_i)(Q_b)(AF)}{(BW)(1000)}$$

Pond and cistern water

$$DHD = \frac{(C_w)(Q_w)(AF)}{(BW)}$$

where DHD = daily human dose, mg/kg/d

C_p = chemical concentration in plant, ug/kg

C_i = chemical concentration in beef or milk, ug/kg

C_w = chemical concentration in water, g/m^3

Q_l = leafy vegetable consumption, kg/d

Q_b = beef consumption, kg/d

Q_c = milk consumption, kg/d

Q_w = water consumption, L/d

BW = body weight, kg

AF = absorption factor, dimensionless

1000 = factor for unit conversion

Human health risks were then estimated using the methodologies for carcinogens and non-carcinogens described in Chapter 2. For carcinogens, the measure of health risk for each chemical was the cancer risk, given by:

$$\text{Cancer risk} = (\text{UCR})(\text{DHD})$$

where UCR = unit cancer risk, $(\text{mg/kg/d})^{-1}$

For the non-carcinogens, the measure of health risk was the adjusted margin of safety for each organ of concern, given by:

$$\text{AMOS} = \frac{\text{ADI}}{\text{DHD}}$$

where ADI = acceptable daily intake, mg/kg/d

For each of the non-carcinogens, the AMOS values were all greater than one, thus predicting that an adverse health effect would not be experienced at these exposure levels. The effects of non-carcinogens were, therefore, not considered further. For carginogens, since there is no threshold below which a prediction of "no adverse health effect" can be made, cancer risks were aggregated for all carcinogens. The estimated cancer risks for fugitive and incinerator stack emissions are shown below in Table 10.

In each case, the risk is of a magnitude not considered to pose a significant human health hazard. Furthermore, the same conclusion can be reached for these exposure pathways when considered in combination, since the combined risks would be less than the one in a million criterion of acceptable risk.

TABLE 10

ESTIMATES OF LIFETIME CANCER RISK FOR

CHRONIC EXPOSURE FROM INDIRECT PATHWAYS

Exposure Pathway	Fugitive Emissions	Stack Emissions
Ponds and Cisterns	2×10^{-8}	2×10^{-7}
Crops	4×10^{-8}	2×10^{-7}
Livestock - Beef	7×10^{-11}	2×10^{-7}
Livestock - Milk	5×10^{-11}	1×10^{-7}

CHAPTER 6

EXPOSURE VIA TRANSPORTATION SPILLS

6.1 PATHWAY DEFINITION AND SPILL FREQUENCY

Direct exposure to toxic pullutants via the air pathway can occur as a result of a spill on the local access route if the spill occurs in proximity to a neighboring residence. Such spills can occur in the transportation of three groups of commodities associated with the OWMC facility: (1) special wastes transported to the facility; (2) reagents and additives transported to the facility; and (3) inter-site transfers of treatment residues in the event that the components of the facility are located at more than one site. An analysis of the relative risks associated with the transportation of these three commodity groups is presented in Appendix E. The analysis indicates that the risks posed by spills of special wastes are significantly greater than those posed by either reagents and additives or inter-site transfers. The generic risk assessment, therefore, was limited to spills of special wastes on the local access route.

Based on reconnaissance studies of the potential local and regional access roads (defined as that part of the access route between the 400 Series Highway and the facility), the closest residences were estimated to be 20-50 m from the centerline of the road in urbanized areas, and 30-160

m from the centerline of the road in the urban fringe and rural areas (M.M. Dillon). Consistent with the conservative approach adopted throughout the risk assessment, human exposure was assessed at the closest estimated distance of 20 m.

The dose received by a human receptor will be directly proportional to the exposure time and concentration. For a spill incident, the exposure time will be determined by one of two factors: the time needed for evacuation of potentially affected individuals from the zone of influence of the spill or the time for cleanup of the spill by an emergency response team. Both these responses are subject to variations, depending on the location and time of the spill, and the rapidity of spill reporting, as well as the location of emergency services. Because of these uncertainties, likely exposure times may vary from several minutes up to several hours. For the risk assessment, the exposure time was assumed to be one hour. This was considered a conservative assumption, given the relatively close proximity of the potential spill sites to the OWMC facility, where response teams and equipment will be located.

As indicated in Chapter 3, transportation spills can occur as a result of both traffic accidents and equipment failures. Traffic accidents were considered to represent a more severe spill scenario for the risk assessment. Unlike the episodic releases associated with facility operations, the data base for transportation accidents is relatively well documented and can be reasonably applied to hazardous waste transportation if the ratio of spills per accident is known. In a study prepared for OWMC (Pilorusso, 1983), a spill rate of 0.196 spills per truck accident

was predicted, and was used for estimating spill rates for risk assessment. Using data for accidents on the local and regional access roads, the truck accident-related spill frequency for special wastes on the local and regional access roads has been defined by the transportation consultants (M.M. Dillon, 1985b) as:

$$S_F = (A_F)(f_{TG})(f_{SA})$$

where S_F = truck accident-related spill frequency

A_F = general vehicle accident frequency

f_{TG} = ratio of accident frequency for trucks to general vehicle accident frequency

f_{SA} = number of spills per truck accident.

These estimates are summarized for the siting options under consideration in Table 11. The spill rate associated with truck accidents was estimated to be 0.017 to 0.331 spills per year for all special wastes. This estimate, however, applies to the probability of a spill of any special waste being transported to the facility. The most hazardous wastes transported to the facility, which contain the surrogate chemical methylene chloride in high concentrations, are UCD categories 211 and 213. These waste categories represent approximately 2450 t/a or 0.8 percent of the projected 300 000 t/a ultimately to be received at the facility. If this factor is applied to the estimated spill frequency, the predicted frequency becomes one spill every 377 to 7353 years, depending on the length of the local and regional access road travelled (as shown in Table 11).

TABLE 11

FREQUENCY OF TRUCK ACCIDENT-RELATED SPILLS OF SPECIAL WASTES ON LOCAL AND REGIONAL ACCESS ROADS

Siting Option	Two-Way OWMC Annual Accident Involvement Frequency	Truck Accident-Related Spill Rate for All Special Wastes	Truck Accident-Related Spill Rate for Methylene Chloride Wastes
LF-9C	2.344	0.230	1.84×10^{-3}
LF-3C	3.380	0.331	2.65×10^{-3}
LF-1E	0.528	0.052	4.16×10^{-4}
LF-1E/PI-27E	0.172	0.017	1.35×10^{-4}
LF-4N/PI-1N	1.411	0.138	1.10×10^{-3}
LF-4N/PI-13N	1.109	0.109	8.72×10^{-4}

Notes: 1) Spill frequency based on 300 000 t/a special wastes transported to OWMC facility.

2) Spill frequency for methyiene chloride wastes based on 0.8% total special wastes.

6.2 EXPOSURE ASSESSMENT AND RISK CHARACTERIZATION

To predict human exposure associated with a transportation spill, dispersion of the surrogate chemical emitted from the spill was estimated using a Gaussian plume model for a ground level source (Turner, 1970).

$$X = \frac{Q}{(\pi)(\sigma_y)(\sigma_z)(u)}$$

Where X = concentration in the air, g/m^3

Q = emission rate, g/s

σ_y = dispersion coefficient in the lateral direction, m

σ_z = dispersion coefficient in the vertical direction, m

u = windspeed, m/s

This model is designed for application to a point source emission. To apply it to the area source constituted by a pool of liquid, a correction is required to approximate the area source as a point source at some distance upwind from the actual spill site. This correction, referred to as the calculation of a virtual point, was estimated by the method of Turner (1970).

In applying the Gaussian plume model to the spill scenario, it was assumed that the topography in the vicinity of the spill site is essentially flat, and that there are no major perturbations introduced by

the proximity of large buildings or other topographic irregularities. The atmospheric conditions assumed for dispersion were stability class F and a wind speed of 1 m/s. Class F reflects the most stable condition and thus accounts for the least amount of chemical dispersion (see Gartner Lee Associates, 1982 for discussion of atmospheric stability classes). Consistent with the approach of using conservative assumptions throughout the risk assessment, F stability was considered appropriate for modeling atmospheric dispersion.

An important component of the dispersion estimate was the choice of dispersion coefficients. These coefficients depend on the distance from the emission source, and are specific to the atmospheric stability class. The use of such dispersion coefficients in a Gaussian model is generally undertaken at distances of 100 m or more, since at shorter distances the behavior of the plume may be significantly influenced by mechanical mixing, particularly for a heavy vapor such as methylene chloride. This limitation was recognized in predicting atmospheric concentrations at distances less than 100 m. The approach adopted here was the use of extrapolated values for the lateral dispersion coefficient and a value of unity for the vertical dispersion coefficient.

From the estimated ambient concentrations, a human dose was calculated as:

$$HD = \frac{(X)(BR)(AF)(t)(1000)}{EW}$$

where HD = dose received, mg/kg

X = air concentration, g/m^3

BR = breathing rate, m^3/hr [See Table 4]

AF = absorption factor, dimensionless

t = exposure time, h

BW = body weight, kg

1000 = factor for unit conversion

Human health risk was then estimated as the adjusted margin of safety (AMOS) using the methodology described in Chapter 2:

$$AMOS = \frac{HD}{(NOEL)\ (Safety\ Factor)}$$

The AMOS value was estimated to be 1×10^{-2}. This value is two orders of magnitude less than one, suggesting the potential for severe health effects, similar to those described for the tank farm fire in Chapter 4 (see page 59), in the event of such exposures. In considering this result, however, it should be recognized that this level of severity is experienced for only 0.8 percent of the special wastes transported, and that these wastes are expected to be involved in a spill only every 377 to 7353 years. Furthermore, in practice the frequency of this scenario will be lower, since not all spills will result in a total loss of truck contents and a large pool, nor will all spills occur at a point on the local and regional access road adjacent to a residence within 20 m of the road.

It is instructive to extend this analysis to consider spills of other waste types that would result in an AMOS value less than one.

Approximately nine percent of all special wastes would fall into this category, and would be expected to be involved in a spill every 34 to 654 years. Thus, it can be concluded that approximately 91% of special wastes transported to the facility do not present any potential for effects via the air pathway in the event of a spill.

CHAPTER 7

CONCLUSIONS

7.1 GENERAL

In the previous chapters, specific risk pathways have been described through which human exposure can occur to toxic pollutants emitted from the operation of the OWMC facility. The predicted exposures have been evaluated in terms of their ability to cause both acute or immediate health damage, and long-term or chronic health damage.

For both fugitive and stack emissions, resulting from the normal operations of the OWMC facility, acute exposures were judged sufficiently low as not to contribute to acute health risk. Therefore, health risk associated with these emissions was evaluated in terms of lifetime cancer risks. In the case of accidents or facility upsets, the reverse was true. These episodic events do not contribute significantly to lifetime burdens of chemical exposure and thus do not significantly affect long-term cancer risk. The exposure levels that result immediately following one of these events, however, may be sufficiently high to cause acute health effects. Thus, in each of these cases, an acute health effect analysis was conducted. The results of both the acute health effects and chronic health effects analyses are summarized below.

7.2 ACUTE EXPOSURES

Risk estimates for acute exposures are presented in Table 12 in terms of the predicted AMOS value. The AMOS, or ratio between the level of exposure expected to result in no effect and the level of exposure predicted as a result of an accident or facility upset, provides an indication of the significance of the predicted exposure.

TABLE 12

RISK ESTIMATES FOR ACUTE EXPOSURES

Source of Release	Duration of Exposure	AMOS
Tank Farm Fire	2.6 h	0.02
Mixing of Incompatible Wastes	42 min	27
Incinerator Stack Scrubber Failure	2 min	
- Sulfur dioxide		0.06
- Nitrogen oxides		2
- Hydrogen chloride		0.5
- Hydrogen fluoride		10
Transportation Spill	1 h	0.01

If the AMOS value is one or greater, the predicted levels of exposure are sufficiently low to avoid the potential for an acute health effect. In cases where the AMOS value is less than one, this is an indicator of the potential for some level of effect, although this may not necessarily be an adverse health effect.

There are three cases in which the AMOS value is significantly less than one: the transportation spill, the tank farm fire and incinerator stack scrubber failure. However, it should be recognized that, at this time, the possible mitigation of these events by modifying the design or operation of the facility has not yet been included. In the case of the incinerator stack scrubber failure, the predicted AMOS values for hydrogen chloride and sulfur dioxide are 0.5 and 0.06 respectively. Based on the application of criteria for establishing short term public limits, no adverse health effects are expected to result from the incinerator scrubber failure, although slight odor or minor, reversible irritation effects might be experienced.

For the tank farm and the transportation spill, the predicted AMOS values are approximately two orders of magnitude lower than one. In both cases, methylene chloride was the surrogate chemical modeled as being released. Also, in both cases, the predicted dose was significantly higher than the short term public limit developed for evaluating adverse health effects. The exact severity of harm that might occur as a result of these exposures is difficult to predict. However, the analysis suggests that the levels of exposure that might result are clearly significant, although not sufficient to cause death or incapacitating illness.

It must also be emphasized that the predicted levels of exposure are based on a number of conservative assumptions used in formulating the exposure scenarios, so that the risk levels are likely overstated. Furthermore, these events are expected to occur infrequently. In the case

of the transportation spill, the level of severity indicated by the AMOS value would only be experienced by 0.8% of the special wastes transported to the facility, and these wastes are expected to be involved in a spill only every 377 to 7353 years. Further analysis indicates that for most wastes (approximately 91%) no effects would be expected even if a spill of the type modeled was to occur. Thus, for 9% of the wastes, some level of effect, ranging from minor effects not considered adverse to health to potentially severe health effects, might be expected based on the conservative modeling performed.

For the tank farm fire, no data are available at this time to provide rigorous analysis of the frequency of occurrence. Review of information from other comparable facilities, however, suggests that the tank farm fire scenario is also a low probability event.

7.3 CHRONIC EXPOSURE

Lifetime cancer risk levels associated with chronic exposure to fugitive air or stack emissions are presented in Table 13. In each case, the conservative assumptions regarding exposure underlying these estimates have been presented in previous chapters. The results indicate that in no case did the predicted levels of cancer risk exceed the criteria for acceptability of one in a million additional lifetime cancers. However, while none of the predicted exposure scenarios lead to unacceptable long-term cancer risks, they should not be treated as equivalent. Rather, the analysis suggests that direct exposure to both stack and fugitive

emissions are more significant than indirect exposure via the consumption of contaminated food or water.

TABLE 13

ESTIMATES OF LIFETIME CANCER RISK FOR CHRONIC EXPOSURE

Exposure Pathway	Fugitive Emissions	Stack Emissions
Direct Inhalation	1×10^{-6}	9×10^{-7}
Ponds and Cisterns	2×10^{-8}	2×10^{-7}
Crops	4×10^{-8}	2×10^{-7}
Livestock - Beef	7×10^{-11}	2×10^{-7}
Livestock - Milk	5×10^{-11}	1×10^{-7}

Several orders of magnitude difference in risk exist between exposure to direct fugitive and incinerator stack emissions and exposure to indirect fugitive emissions. In the case of indirect exposures to stack emissions, the levels of predicted risk are closer to those associated with either direct exposure to fugitive or stack emissions. This is a direct consequence of including in the risk assessment the formation and emission of dioxins during the incineration process. However, while the potential presence of dioxin emissions increases the levels of risk associated with indirect exposure to stack emissions, the overall pattern of these results suggests that greater health risks for stack emissions are associated with direct exposures than with indirect exposures.

In addition to performing comparisons between selected risk pathways, it is useful to evaluate the predicted risk levels by comparing them to risk levels associated with other human activities. Presented in Table 14 are the lifetime risks associated with a number of different phenomena. In some cases, the reported risks are associated with voluntary human activities, such as smoking or eating charcoal broiled meat. In other cases, the risks are related to occurrences which essentially are involuntary experience, such as being struck by lightning or receiving normal background radiation. Compared to any of these risk levels, it is evident that the health risks predicted for the operation of the OWMC facility, based on a series of conservative assumptions, are less significant than risks normally and routinely experienced.

7.4 RANKING OF RISK FACTORS

The outputs of the risk assessment, provided in Tables 12 and 13, can be used directly in the factor ranking process. In order to evaluate the significance of each of the risk values derived in the risk assessment, three variables -- severity, frequency, and mitigation -- must be considered.

Severity refers to both the magnitude of the risk created by exposure and the nature of the illness produced. For example, a cancer risk of 1×10^{-6} is clearly more severe than a risk of 1×10^{-11}. Likewise, irritation of the nasal passages is clearly less severe than incapacitating illness or death. Therefore, each effect related to exposure can be ranked in terms of the degree of severity.

TABLE 14

RISKS OF DEATH FROM VOLUNTARY AND INVOLUNTARY EXPOSURES

Source of Exposure	Lifetime Risk[a]
ACCIDENTAL RISKS OF DEATH[b]	
All home accidents	7.7×10^{-3}
Lightning	3.5×10^{-5}
Fire arms (accidents)	7×10^{-4}
Motor vehicle accidents	1.68×10^{-2}
Electrocution	3.71×10^{-4}
CANCER RISKS FROM RADIATION EXPOSURES	
Average medical diagnostic x-ray	1.4×10^{-3}
Background radiation exposure (average U.S., sea level)	1.4×10^{-3}
Frequent airline passengers - 4 hours/week (cosmic rays)	7×10^{-4}
Excess cancer risk due to living in masonry building rather than wood	3.5×10^{-4}
CANCER RISKS FROM COMMON CARCINOGENS	
Person sharing room with smoker	7×10^{-4}
One pint of milk per day (aflatoxins)	1.4×10^{-4}
1/2 lb charcoal broiled steak/week (cancer only; heart attack etc., extra)	2.1×10^{-5}
Average smoker (cancer only)	8.4×10^{-2}
(all effects)	2.1×10^{-1}
All cancers	1.96×10^{-1}

Source: E.A.C. Crouch and Wilson. (1984).

Notes: a) All statistics based on U.S. data

b) Lifetime accidental risks based on annual values for a sequence of several years.

The second variable is the frequency of occurrence. Some emissions that produce adverse health effects are episodic in nature. They occur with a greater or lesser frequency depending on the nature of the event being considered (for example, incinerator scrubber failure may occur more frequently than a tank farm fire). Other emissions occur on a continual basis, such as incinerator stack or fugitive emissions. Therefore, in the case of emissions that are episodic, the frequency of occurrence is an important variable to consider in factor ranking.

The third variable of concern is mitigation potential. Some of the adverse health consequences predicted by the risk assessment are the result of exposures which can be mitigated while others are not. The direct inhalation pathway, for example, is one for which no readily available mitigation strategy is available to prevent exposure. Conversely, the ingestion of contaminated water from ponds and cisterns can be prevented and, thus, the risk associated with this exposure precluded. The potential for mitigation, therefore, is a variable to consider in factor ranking.

Each of the risk pathways presented in Tables 12 and 13 were evaluated considering the three variables described above. The results of that evaluation for both the chronic and acute exposure pathways are presented below.

CHRONIC EXPOSURES

In the case of chronic emissions that lead to increased cancer risks, the frequency of occurrence is not a variable which affects the ranking of

these pathways since all result from chronic or continuous exposures. However, the severity of impact and the opportunity for mitigation are clearly different for each of the pathways. Since cancer is the health end-point of concern, the severity variable cannot be used to distinguish between the type of health injury produced, but rather to distinguish the frequency of expected incidence of disease. Using this criterion, it is evident that direct exposure produces a more severe effect than any of the indirect exposure pathways. Furthermore, in the case of each of the indirect exposure pathways, steps can be taken to mitigate against exposure, while for direct exposure such steps are not readily available. Therefore, based on both severity and potential for mitigation, the direct pathway for chronic exposure ranks as more significant than any of the indirect pathways.

A distinction can also be made between different indirect pathways, particularly with regard to fugitive emissions. As noted above, the risks associated with indirect exposure to stack emissions are essentially equal and reflect consideration of the potential emission of dioxins from the incineration process. However, in the case of fugitive emissions, there are significant differences among the severities predicted for the indirect pathways. Exposures to contaminants through the ingestion of contaminated water from ponds and cisterns, or the ingestion of contaminated crops, produces a more severe impact in terms of cancer risk levels than the ingestion of livestock meat or milk (see Table 13 above). For all indirect pathways, the potential for mitigation exists and, therefore, this variable cannot be used to rank the relative significance of the different indirect pathways.

In summary for the chronic exposures, the results of the analysis of direct and indirect pathways suggest that in the factor ranking process greater weight should be given to the potential for direct exposures versus indirect exposures. In addition, within the indirect exposure group, for populations potentially affected by fugitive emissions, greater weight should be given to potential exposures to contaminants through the ingestion of contaminated water and crops than through the ingestion of contaminants in livestock meat or milk.

ACUTE EXPOSURES

The analysis of acute health risk pathways (see Table 12) suggests that distinctions between these pathways also can be made. The situation which produces the least concern is the mixing of incompatible wastes, since the AMOS value calculated for this accident condition is 27, which is significantly greater than the threshold value of one. In the other three cases (the scrubber failure, the tank farm fire, and transportation spill) for which the AMOS values are less than one, the significance of severity of effects, frequency of occurrence, and mitigation potential are considered further below.

In the case of the incinerator scrubber failure, while the AMOS values are less than one, application of criteria for establishing short term public limits indicates that no adverse health effect would result, although slight odor or minor, reversible irritation effects might be experienced. Information on frequency of scrubber failure events is limited, although they are expected to occur less infrequently than the tank farm fire or transportation spill events. Mitigation potential is

limited by the short duration of the upset condition (2 minutes) which, however, contributes to the minor nature of the effects experienced by an exposed population.

For the transportation spill, the AMOS value is significantly less than one, and consideration of short term public limits for assessing adverse health effects suggests that potentially severe health effects could be experienced at the point of maximum exposure. Transportation spills, however, are expected to occur relatively infrequently; as discussed in Chapter 6 (see page 76), the predicted spill frequency corresponding to the AMOS value is one spill every 377 to 7353 years. In addition, the potential for mitigation exists so that the severity of health impact predicted as a result of a transportation accident can be reduced from that predicted here. For example, if rapid emergency response to a spill event occurs, the period of exposure can be reduced, thus reducing the potential for adverse health impact. Therefore, while certain transportation spill events are capable of causing significant adverse health effects, the frequency at which they occur is very low and there is the potential to mitigate against their effects.

The tank farm fire analysis presented in this report is premised on the release of methylene chloride as was the transportation spill accident. In this case, too, the AMOS value is significantly less than one, and consideration of short term public limits similarly suggests that potentially severe health effects could be experienced at the point of maximum exposure. No data are available on the frequency of such an event, although the probability is believed to be extremely low. As with

the spill event, the potential for mitigation exists such that emergency response to the fire situation or evacuation may reduce the period of exposure. The tank farm fire can thus be considered to pose a concern similar to that of the transportation spill since both have the potential for significant adverse health effects, their frequency of occurrence is expected to be low, and there is the potential to mitigate against their effects.

In summary for the acute exposures, the most important differences in the acute exposures considered are in the severity of potential effects. In the case of the transportation spill and tank farm fire, potentially adverse health effects are predicted; for the incinerator scrubber failure, only minor reversible effects are predicted; and for incompatible waste mixing, no effects would be expected. While there are other differences among the acute exposures, i.e., in their frequency of occurrence and mitigation potential, the severity ranking is considered the appropriate order of their relative significance.

A final point of comparison to be considered is the relative importance of the acute and chronic exposure pathways. There is, however, no scientific basis on which to make such comparisons. Their relative importance depends on subjective judgements as to the significance of acute health effects caused by an event of known probability versus a known likelihood of increased incidence of long term disease, in this case cancer resulting from continuous exposure. Judgements of this sort are considered beyond the scope of this report, although the information provided here will facilitate such policy decisions by OWMC.

In conclusion, factor ranking is an important process in site selection. The information provided in this risk assessment document allows comparison between different risk pathways and permits rankings to be made based on severity of effect, frequency of occurrence, and mitigation potential. Such information is directly useful in the factor ranking process and, ultimately, in site selection.

GLOSSARY

Acceptable Daily Intake (ADI)	Estimate of the largest amount of chemical to which a person can be exposed on a daily basis which is anticipated to result in no adverse effects (usually expressed in mg/kg/day).
Acute Exposure	Exposure of short duration, as opposed to chronic.
Adjusted Margin of Safety (AMOS)	Estimate of the largest amount of chemical to which a person can be exposed which is not anticipated to result in effects (usually expressed in mg/kg/day) divided by the actual amount of human exposure.
Carcinogen	A substance that increases the risk of cancer.
Chronic Exposure	Exposure of long duration, as opposed to acute.
Conservative Assumption	Assumptions which are conservative in the sense of overestimating possible human health risk.
Dose	Measurement of the amount received by the subject, whether human or animal, per unit of body weight.
Dose-Response Evaluation	A component of risk assessment that describes the quantitative relationship between the amount of exposure to a substance and the extent of toxic injury or disease.
Dose-Response Relationship	The quantitative relationship between the amount of exposure to a substance and the extent of toxic injury produced.

Emergency Exposure Limit (EEL)	Limits applicable to unpredictable short-term exposures which, if not exceeded, may result in nonincapacitating, reversible effects, but avoid significant decrements in performance during emergencies (see SPTL).
Epidemiological Study	Study of human populations to identify causes of disease. Such studies often compare the health status of a group of persons who have been exposed to a suspect agent with that of a comparable non-exposed group.
Exposure	To be accessible to the influence of a chemical or chemical action.
Exposure Assessment	A component of risk assessment that involves describing the nature and size of population exposed to a substance and the magnitude and duration of their exposure. The assessment could concern past exposures, current exposures, or anticipated exposures.
Extrapolation	The estimation of a value beyond the known range on the basis of certain variables within the known range, from which the estimated value is assumed to follow.
Fugitive Emissions	Emissions generated by residual losses from pollution control devices and miscellaneous uncontrolled sources. Excludes incinerator stack emissions.

Hazard Analysis	The systematic identification of potential accidents and upset conditions of industrial facilities, and the quantitative analysis of their probability (using techniques such as "fault tree" analysis) and consequence. This terminology is applied typically in the chemical and nuclear industries, and should not be confused with "hazard evaluation" (see below).
Hazard Evaluation	A component of risk assessment which involves gathering and evaluating data on the types of health injury or disease (e.g. cancer) that may be produced by a chemical and on the conditions of exposure under which injury or disease is produced.
High-to-Low-Dose Extrapolation	The process or prediction of low exposure risks from the measured high exposure-high risk data.
Human Health Risk	The likelihood (or probability) that a given exposure or series of exposures to a toxic substance will damage the health of individuals experiencing the exposures.
Ingestion	Type of exposure through the mouth.
Inhalation	Type of exposure through the lungs.
Interspecies Extrapolation Model	Model used to extrapolate from results observed in laboratory animals to humans.
Leachate	Aqueous liquid generated by infiltration of rainwater or snowmelt into landfilled wastes.

GLOSSARY - Continued

Lifetime Exposure	Total amount of exposure to a substance that a human would receive in a lifetime (usually assumed to be seventy years).
Local and Regional Access Road	That portion of the access route between the 400 series highway and the facility.
Margin-of-Safety (MOS)	Maximum amount of exposure producing no measurable effect in animals (or studied humans) divided by the actual amount of human exposure.
Mathematical Model	Numerical procedure used during risk assessment to perform extrapolations.
No-Observed-Adverse-Effect-Level (NOAEL)	Dose level at which no adverse effects are noted.
No-Observed-Effect-Level (NOEL)	Dose level at which no effects are noted.
Potency	Amount of material necessary to produce a given level of a deleterious effect.
Products of Incomplete Combustion (PICs)	Chemicals formed as a result of partial oxidation of chemicals in the waste feed due to the combination of molecular fragments outside the combustion zone.
pH Excursion	Deviation from normal pH conditions during a chemical treatment process.
Risk	Probability of injury, disease, or death under specific circumstances.

Risk Assessment	The scientific activity of evaluating the toxic properties of a chemical and the conditions of human exposure to it, both to ascertain the likelihood that exposed humans will be adversely affected and to characterize the nature of the effects they may experience.
Risk Characterization	Final component of risk assessment that involves integration of the data and analysis involved in hazard evaluation and human exposure evaluation to determine the likelihood that humans will experience any of the various forms of toxicity associated with a substance.
Risk Management	Decisions about whether an assessed risk is sufficiently high to present a public health concern and about the appropriate means for control of a risk judged to be significant.
Risk Pathway	Describes pathway by which chemical release into the environment is transported to a human receptor.
Route of Exposure	Method by which the chemical is introduced into the biological organism, e.g. inhalation, ingestion, skin absorption, etc.
Safe	Condition of exposure under which there is a "practical certainty" that no harm will result in exposed individuals.
Safety Factor	Adjustments to the experimentally observed NOEL to compensate for uncertainties in the data and for imprecision in extrapolation to the general human population.

Scientifically Plausible	An approach or concept having substantial scientific suppport but is not completely certain.
Short Term Exposure Limit (STEL)	A 15-minute time-weighted average exposure which should not be exceeded at any time during a workday even if the 8-hour time-weighted average is within the TLV.
Short Term Public Limit (STPL)	Limits applicable to predictable single exposures of short duration which, if not exceeded, are expected to be associated with, at most, a nonincapacitating, reversible effect (see EEL).
Special Wastes	Industrial wastes that cannot be adequately dealt with by the existing public facilities such as municipal sewage treatment plants, municipal incinerators and municipal landfills.
Surrogate Chemical	Chemicals chosen to represent the most hazardous waste constituents to be managed at the OWMC facility.
Systemic Effects	Effects observed at sites distant from the entry point of a chemical due to its absorption and distribution into the body.
Teratogen	A chemical or agent that causes physical defects in the developing embryo after maternal exposure to the chemical.
Threshold Dose	The dose that has to be exceeded to produce a toxic response.

Threshold Limit Value (TLV)	Time-weighted average concentration for a normal 8-hour workday and a 40-hour workweek, to which nearly all workers may be exposed repeatedly, day after day without adverse effect.
Toxic	Harmful in regard to the effects of chemicals.
Unit Cancer Risk (UCR)	Estimate of the lifetime risk due to each unit of exposure in the low exposure region.

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